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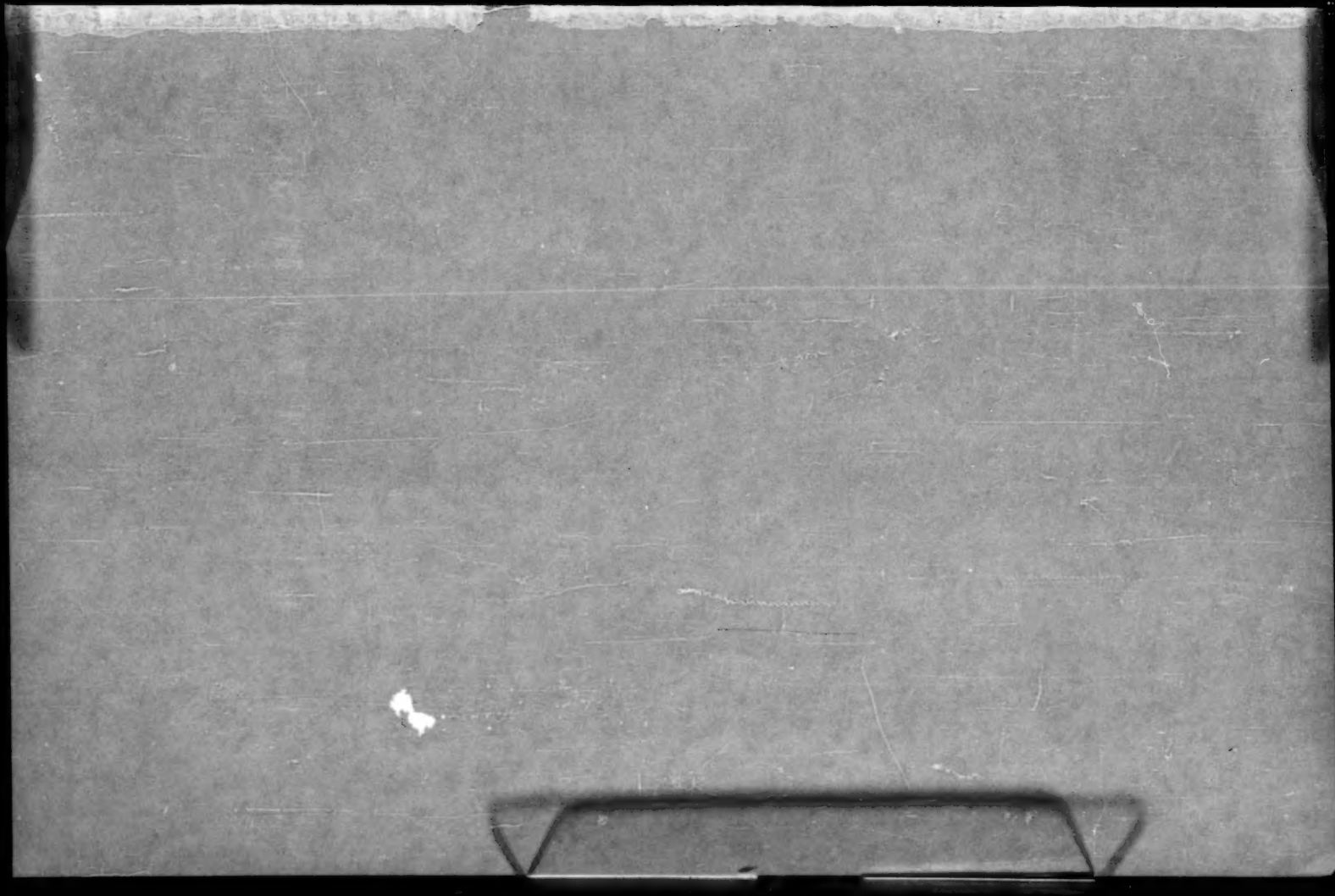

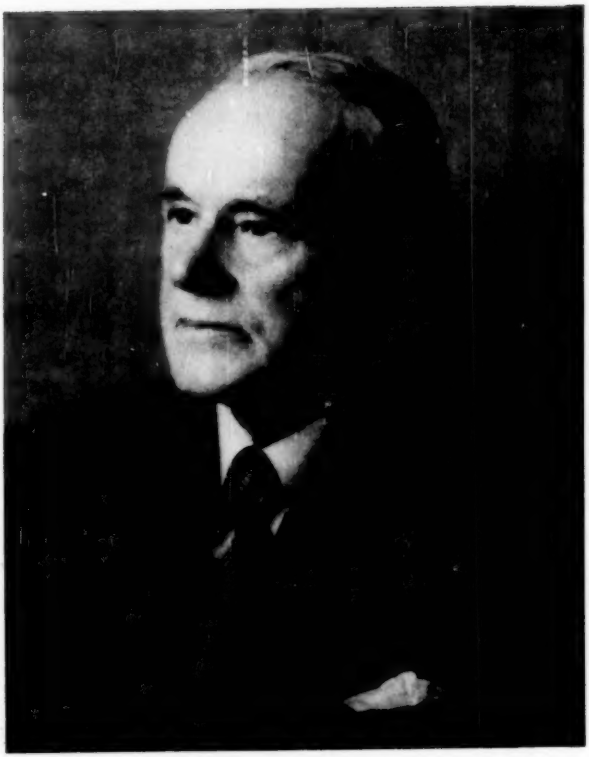

James Dewar

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THE PSYCHOLOGICAL REVIEW

JAMES DREVER

1873–1950

Emeritus-Professor James Drever was undoubtedly one of the outstanding psychologists of his generation, and his influence on the progress and development of psychology can never be estimated. His death, on August 10th, 1950, was a grievous loss, not only to the science which he had made his own, but to many colleagues and friends in different parts of the world.

Professor Drever was born on April 8th, 1873, on the island of Shapinsay, one of the Orkney Islands off the north coast of Scotland. He was always proud of being an Orcadian, as all who came into contact with him realized, and any event connected with his native islands was sure to evoke in him a more than passing interest. After his illness in 1948 when he was prevented from presiding over the meetings of the XII International Congress of Psychology at Edinburgh, his one ambition on leaving the nursing home was to breathe once more the refreshing air of Orkney, which, he was convinced, would renew him immediately in body and in mind.

His attachment to his native islands persisted through life, and was revealed not only in his love of the sea and sailing, but in his interest in linguistics. He experienced great delight in tracing, for example, Scandinavian and other influences revealed perhaps in a different turn of phrase as between the Orkney Islands and the mainland of Scotland. This love of words spread to studies of other languages. He became proficient in reading scientific articles in a number of languages, and it was fairly common to find him puzzling away at a grammar in some new language he was determined to master in order to read an article in the original.

Professor Drever was led to a study of psychology from the adjoining sphere of education. After his first graduation as Master of Arts at Edinburgh University, the teaching profession claimed him and he taught in various schools where he acted as assistant teacher and later as headmaster over a period of ten years. An invitation to become assistant to the late Professor Darroch, Professor of Education in the University of Edinburgh, was extended to him, and he accepted. This was an alliance which bore fruit some years later in the establishment of an Honors Post-graduate Degree in Psychology and Education, the Bachelor of Education. During this time Professor Drever studied for the B.Sc. degree of London, and was awarded First Class Honors in Psychology in 1909.

For twelve years Mr. Drever, as he was then, and Professor Darroch worked together, and during that time he lectured mainly on topics in the field of education. His courses were two: a course on Greek and Roman Education, and one on Present Day Problems in

Education. Concurrently he delivered lectures on psychology to students in training as teachers in Moray House Training College, Edinburgh. During this period his first contributed papers began to appear; one of them was a paper on "Kinds of Attention," which was largely a criticism of Stout's classification of attention as formulated in his *Groundwork of Psychology*. The first book written by Professor Drever also made its appearance about this time, a small book on *Greek Education* published by the Cambridge University Press.

A new development took place in 1912 in the establishment of a pedagogical laboratory in Moray House Training College, one of the earliest to be established in the country. The laboratory was equipped with apparatus such as a Hipp chronoscope, an ergograph, a pendulum tachistoscope, memory apparatus, etc., and was intended for use by research and advanced students. Professor Drever was placed in charge, and soon work began on analytical studies of writing and reading, children's vocabularies, etc., some of the results of which appeared in scientific journals. His monumental work, *Instinct in Man*, gained for him the degree of Doctor of Philosophy (D. Phil.) in 1916, and marked him as a psychologist of the first rank.

The break away from education into psychology came with the appointment of Professor Drever to the lectureship in Psychology at Edinburgh University in 1918 on the death of Dr. W. C. Smith, and the lectureship included headship of the Department. As the Department developed, the lectureship became a readership, and ultimately a Chair, to which Professor Drever was appointed in 1931 as the first occupant, and which he held until his retirement in 1945.

The development of psychology in Edinburgh and the recognition of the importance of the Psychology Department in University circles and beyond are owing to the energy and initiative of Professor Drever. One of his characteristic traits was to do as well as possible any task undertaken whether it was service on a committee or a lecture to be delivered to an outside association. This spirit of "work well done" underlay all his activities and is responsible for the tremendous growth of the Department under his guidance. The number of staff, students and courses all increased, and from a modest department with a staff of two and some 70 or 80 students, the Department increased to a staff of five or six with additional part-time members, and in a peak year to a student body of about 600. Additional honors courses became available, and students were able to study for the degree of Bachelor of Science or Master of Arts with Honors in Psychology, or, if trained teachers and graduates, for the post-graduate degree of Bachelor of Education. More advanced students were attracted to the Department and engaged in research for the Degree of Doctor of Philosophy. These developments are a tribute to the intrinsic value of the courses given in psychology by its distinguished professor and the standing they gradually acquired in the scientific world.

Professor Drever laid great emphasis on the development of psychology as an experimental science. All his students received sound teaching both in fundamental problems of psychology and in experimental psychology. Professor Drever was well aware of the value which accrued from training in experimental techniques, and students in their first year of psychology were compelled to attend, as part of the course, sessions in which various psychological phenomena were studied from the experimental angle. Similar sessions were instituted as part of the Honors courses in psy-

chology, and each Honors student was required to devote six hours weekly to experimental psychology. Former students now in important posts in different spheres and in all parts of the world have paid tribute from time to time to their thorough training in experimental psychology, and have expressed keen appreciation of its value to them.

Professor Drever's activities were not confined only to the George Combe Department of Psychology. He soon realized that psychology involved more than theoretical discussion, and so we find him becoming interested in the problems of juvenile delinquency. As far back as 1925 he set up in the Department the nucleus of a clinic for the study of delinquent children. This step immediately met an urgent need in the community, and from this small beginning there soon developed a fully-organized Child Guidance Clinic, staffed on a voluntary basis by the members of the Psychology Department, but working in collaboration with other experts who volunteered their services: psychiatrists, pediatricians, social workers, and play-room attendants. The establishment of this pioneer voluntary clinic pointed the way, and led to the establishment of child guidance clinics in Edinburgh and in other parts of the country.

Other projects clamored for attention, and soon the staff was busy, on the initiative of Professor Drever, in the administration of a battery of psychological tests to all apprentices who desired to enter the printing trade, one of Edinburgh's most famous industries. This scheme was welcomed by both employers and employees of the printing industry, and has proved invaluable in the selection of apprentices. It has now been in operation for over 20 years, and has been extended to other areas in Scotland and England.

A different interest was the research undertaken by Professor Drever on studies of deaf children. On the initiative of a headmaster of one of the local institutions for the deaf, he was asked to devise some method of assessing their abilities for purposes of instruction, and for use in vocational guidance. This investigation soon spread to other schools for the deaf in Scotland, and then teachers of the deaf in England became interested. The final outcome of the research was formulation of a scale of performance tests for administration to both deaf and hearing children which is used extensively today throughout the British Isles and in the colonies. Other problems connected with the deaf child attracted his attention, and some of his conclusions are recorded as articles in *The Teacher of the Deaf.*

The blind child also gained his sympathetic interest, and for a number of years Professor Drever served as Chairman of the Royal Blind Asylum and School, Edinburgh. His advice was invaluable, and many improvements in the teaching and care of the blind are the result of his wisdom and insight. A later and related project which he entered into wholeheatedly was the erection near Edinburgh of a training center for the war-blind. This was no easy task, and many hours were willingly spent in organizing and bringing to fruition this ambitious scheme. The Scottish National Institute for Blinded Ex-Servicemen, now satisfactorily established, is a lasting tribute to Professor Drever's purposefulness and his public-spiritedness. He was held in high esteem by the staff of the Institute and by the blinded men who found in him one who had sympathy with their personal difficulties and who was ever ready to lend a helping hand.

During his lifetime Professor Drever held many positions of honor. He was appointed President of the British Psychological Society, and during his tenure

of office (1935–1938) helped to guide its policy. He was also instrumental in inaugurating the Scottish Branch of the Society, of which he was the first President. He was a faithful attender of the meetings of the British Association for the Advancement of Science, and served on a number of its research committees. He became President of its Psychology Section in 1926 and delivered an address on the penal system and its psychological implications. Other important posts reveal the extent of his activities: member of the National Advisory Council for Scotland on Physical Training, of the International Examinations Inquiry, of the Advisory Committee of the Selection of Personnel Branch at the War Office, of the Scottish Council for Research in Education, of the Scottish Association for Mental Health, and President of the Scottish Child Guidance Council. He was a Fellow of the Royal Society of Edinburgh, and in 1938 the King of Norway honored him by making him a Knight of the First Class of the Royal Norwegian Order of St. Olav.

His life was one of constant endeavor, and every minute counted; yet he was always ready to give the benefit of his experience to anyone seeking advice or assistance. He was unable to suffer fools gladly, but any genuine enquirer after knowledge was sure of guidance and a sympathetic interview. His boyish enthusiasm, his spontaneous laughter, and his delight in trying out intricate circuits in the set-up of experiments will long be remembered by his Honors students and colleagues. He was an indefatigable worker, and experienced great joy in work. He spared neither himself nor his staff. Those in close contact with him were continually amazed at his tirelessness. He had an alert mind, showed a quick grasp of any intricate problem, and enjoyed debate. His sincerity and integrity are well-known, and he brought to any problem an unprejudiced and unbiassed outlook. He endeared himself to his students by his unassuming manner, his tolerance, his friendliness and easiness of approach. Former students kept in touch with him over the years and became his friends.

His contribution to psychology is considerable, both in directing its development by his own outstanding genius, and by the influence exerted on many thousands of students. Those of his students who specialized in psychology are now in turn guiding others in all quarters of the globe. His books and articles are numerous, and many of the former have gone through many editions. Before his death he had just completed a *Dictionary of Psychology* which is at present in the press, and which will be of considerable value to all psychologists. For a number of years he was Editor of the *British Journal of Psychology Monographs*, and Assistant Editor of the *British Journal of Psychology*. He was also Associate Editor of two American psychological journals.

The death of Professor Drever is a loss to psychology and to psychologists. His wise counsels were heard with respect by old and young. His many acts of unobtrusive kindness in helping young psychologists can never be told, but his gracious presence will linger in the memory of all who had the privilege of knowing him. The world has lost not only a genial personality, but an eminent scholar of international repute, and a psychologist of the highest rank.

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HOMEOSTASIS AS A UNIFYING CONCEPT IN PERSONALITY THEORY

BY ROSS STAGNER

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The task of personality theory is to achieve generalizations having maximum applicability with maximum predictive value. Such generalizations may relate to personality as a feature of all human organisms, or to personality as the unique totality of a single individual. The most fruitful generalizations would seem to be those which are useful in both of these areas.

It is proposed here that the principle of homeostasis—the law that organisms seek to maintain constancy of inner tissue conditions—can be expanded into a major generalization in the field of personality theory. This principle can be shown to have value in illuminating personality considered both as a universal and as a unique phenomenon.

While the concept of homeostasis in itself needs no restatement here, the particular sequence of ideas to be developed calls for a beginning at the basic physiological level. Treating this very briefly, we shall then discuss in more detail some broader implications of the concept.

Homeostasis was first identified as a major biological concept in connection with the maintenance of essential tissue equilibria, such as the oxygen, temperature, glucose and other inner constants (31, 8). These inner constancies correspond to the basic biological needs upon which behavioristic theorists develop their conception of personality dynamics.

According to this view, any disturbance of essential constancy leads to tension, restless activity, contacting the needed substance, and restoration of equilibrium. As metabolism consumes glucose, for example, the hunger tension arises. Seeking-behavior results in the location and ingestion of food; the return to equilibrium is accompanied by quiescence.

It is, however, obvious that the organism does not simply continue to restore those biological equilibria which are essential to the existence of our protoplasm. While critics of homeostatic theory have suggested that this view offers only a static explanation of behavior, a recurrent restoration of a pre-existing state, such interpretations are unfair to the theory. When a given tissue constancy is first disturbed, the organism mobilizes energy for action which ceases when the equilibrium is restored. *Recurrence* of this same disturbance is another matter. (1) The organism percieves minimal physiological changes as *cues* and *anticipates* the disturbance. Forestalling action therefore becomes possible. (We eat before we experience intense hunger pangs.) We suggest that energy mobilization for forestalling tactics must be explained in terms of a *cortical tension* which reflects the visceral-proprioceptive pattern of the original biological disequilibration. (2) The organism perceives environmental objects as potential sources of equilibrium-restoration and behaves differently toward them (hoarding food, building houses or nests, etc.). Thus, repeated disequilibration results in continuous modification of the organism and its perception of the external world. *Dynamic homeostasis* involves the maintenance of tissue constancies by establishing a constant physical environment—by reduc-

ing the variability and disturbing effects of external stimulation. Thus the organism does not simply restore the prior equilibrium. A new, more complex and more comprehensive equilibrium is established.

But it is not only the changes in physical situations which disturb tissue constancies. Persons become increasingly important to us from birth onward. To the infant the presence of mother is a *sign* of tissue constancy and physical-milieu constancy. The absence of mother becomes a sign of disequilibrium and threat. Thus, the mother's appearance, voice, etc., can become valued as a means to biological equilibrium. In the same way other changes in the social environment may come to function as signals for biological disturbance, and set off anxiety tensions, energy mobilization, and vigorous action toward the restoration of social-milieu constancy (12). The organism may then take anticipatory measures to prevent change in the *social* environment on subsequent occasions.

This sequence of events leads to the view of personality sketched in Figure 1, where it is suggested that the individual, dynamically striving to preserve his inner tissue constancies, moves successively to build a constant physical environment (second level), and a constant social environment (third level). These may be thought of as envelopes protecting the biological constancies. It is assumed that, in the typical sequence, demand for physical constancy emerges first and demand for social constancy second, the latter being based in considerable part upon the need for physical uniformity. This leads to the prediction that threats to the organism's physical environment will generally produce more vigorous energy-mobilizations than threats to the social constancies; and that actual biological disequilibrium will dominate over either of the others. For the most part this prediction is verified: under the pressure of physical hazard, social amenities disappear (13); and under extreme hunger or pain, the physical environment is likely to be disregarded. We shall consider later the case in which this prediction is not verified.

HOMEOSTASIS AND PERCEPTUAL CONSTANCY

Before elaborating further on the motivational aspects of homeostatic theory, it is desirable that we introduce a new thread into the pattern. An important part of stage two (the establishment of a constant physical milieu) is perceptual in character. The so-called "perceptual constancies" (size constancy, color constancy, etc.) must be introduced here if we are to get a clear picture of the extensive role played by the homeostatic principle in personality organization.

Every undergraduate student of psychology learns that objects tend to be visually perceived as having a constant size, shape and color under varying illuminations and at varying distances. It is noted that these external conditions make it physically impossible to have a constant retinal image; perceptual constancies are therefore central in basis. The teacher does not always point out to the undergraduate that such constancies have survival value; but it is fairly obvious that man could not have survived under primitive conditions if he failed to identify the small image of a saber-tooth tiger before it reached the size associated with immediate physical danger.

When observed from this point of view, the perceptual constancies appear to be another facet of homeostasis. The organism needs a constant external environment if it is to maintain constant tissue states. In attempting to reduce the variability of external stimuli

(threats to equilibrium or sources of needed substances), the organism must deal with objects. But objects, as stimuli affecting the distance receptors, are protean in size, shape and color. Under such conditions adjustment is most difficult. The organism therefore *learns* to perceive identical objects as possessing these constant attributes.

The excellent treatment by Hebb (18) of the problem of perception has made it unnecessary to defend this suggestion. As Hebb has noted, the Gestalt emphasis on native factors in object perception should be restricted to the perception of *unity;* that is, the awareness of form and closure. The evidence he cites bears rather convincingly on the notion that *identity* must be a product of learning; indeed, it would seem that more than normal faith in mysterious organismic powers would be required to explain size-constancy on a nativistic basis.[1]

Hebb has placed rather less emphasis than seems justified upon the fact that perception is itself a purposive, need-directed process dominated by organismic homeostasis. It is interesting in this connection to consider the work of Adelbert Ames, Jr. (3), and the variety of research activities stimulated thereby (9, 17, *et al.*). It appears from these findings that even so simple a perception as that of two lines of light in a dark room is modified by the set or purpose of the observer, and that the perceived characteristics (size, shape and distance) of objects inhere in their relations to the purpose of the perceiver. Since—as the first section of this paper indicated—purposive activities can be subsumed under the homeostatic category, this line of reasoning confirms the view that the perceptual constancies are also to be considered as homeostatic manifestations.

Helson (19) has argued persuasively, and the data of other researchers agree, that the frame of reference of the individual tends toward a constant organization about a point determined by the geometric mean of his experiences with the class of stimuli presented. This suggests that the organism builds not merely a constancy for characteristics of individual objects, but also constancy for classes of objects. Thus Hastorf (17) notes that subjects make a projected rectangle of light larger when operating under the task-set of representing an envelope than when representing a calling card.

This is possibly the explanation for the finding of Bruner and Goodman (7) that poor children make a circle representing a 25-cent piece larger than it is made by well-to-do children. It may be that the "physically real" value (purchasing power) was greater for the poorer children; thus constancy would favor the larger size.

Physical perception of objects, and of classes of objects, as possessing constant characteristics, will aid survival. It becomes possible to contact needed substances and avoid noxious stimuli, to deal adaptively with physical reality; whereas reactions based directly upon the protean, ever-changing peripheral receptor process would induce only behavioral confusion.[2] We must maintain external as well as internal constancy.

[1] There is even reason, according to Raney and Carmichael (29, p. 16), to believe that both sensitivity and response are determined initially by inner, metabolic factors; and that outside stimuli acquire "meaning" in their function of interrupting or facilitating such endogenous behavior.

[2] We are intrigued, in this connection, with the work reported by Eysenck (11) and others on dark-vision of anxiety neurotics. It appears that such patients show a far greater loss of visual efficiency under dark adaptation than normals or hysterics. Could this be due, in anxiety cases, to the presence of a deep insecurity about these perceptual constancies? Does it mean that children who, for any reason, fail to stabilize firmly these percepts—under widely varying physical conditions—are prone to develop anxiety neurosis?

CONSTANCIES IN SOCIAL PERCEPTION

Perceptual constancies may very well contribute in a major way to the establishment of the uniform social milieu which has been suggested as the third level of homeostatic adjustment. Successful adaptation of the child to demands of his parents is unquestionably facilitated if he behaves on a "constancy hypothesis" with respect to them. Where reality constantly frustrates this tendency (very inconsistent real behavior by a parent), maladjustment seems invariably to result.

In later social development the same pattern appears. Our perception of individual personalities follows the constancy principle. If I observe Mr. Smith behaving in a weak, futile, ineffectual manner today, I shall be predisposed to perceive those same characteristics in his actions tomorrow (the so-called "halo" effect). This phenomenon is likewise adaptive and homeostatic in character. The person, in his efforts to achieve tissue constancy, must operate on some hypothesis as regards external reality. Since the constancy hypothesis proves useful in dealing with inanimate objects, it tends to be transferred to dealing with people. Further, infantile experiences usually reinforce the constancy hypothesis. Mother has a dependable relationship with food, comfort and security. Strangers are often associated with disturbance of equilibrium, thwarting of needs, pain, discomfort and insecurity. Thus the perception of specific individuals, and of classes of people, may become organized as constants and this may aid in adjustment. Unfortunately, or fortunately, as one chooses to view the phenomenon, humans do not in reality manifest such constancy as does an inanimate object. The perception of personality-constancy is thus projective and inaccurate in many instances, but is adhered to nevertheless.

Once a delineated percept for a given individual or group is established, it tends to persist. We overlook in our friends behavior that we bitterly criticize elsewhere. Undesirable characteristics simply are not perceived. Conversely, disliked individuals are seen as having "bad" traits even when no objective basis for this perception can be identified.[8]

Leeper (24) demonstrated the establishment of a constant percept for an ambiguous figure. By showing a picture which allowed only one alternative (from the ambiguous drawing) to be seen, he was able to fix the perception so that it was virtually impossible for subjects to get the other object. Edwards (10) verified the existence of a selective tendency based on established perceptions, tending to maintain constancy. He presented a speech containing an identical number of pro-New Deal and anti-New Deal statements to his subjects. Republicans remembered mostly anti-New Deal items (and distorted some favorable remarks into hostile comments); Democrats remembered pro-New Deal facts and ignored the others. Thus a percept of an idea or social object, once established, obeys the constancy principle.

The effect of reality (experience followed by action directed toward the object) no doubt is in the direction of modifying constancies established on an unrealistic basis. This process, in the field of physical reality, probably proceeds promptly and reliably. In social perceptions it is slower and less dependable. As the various studies of stereotypes of social groups indicate, such pictures develop without much basis in reality. Even when world events clearly

[8] A methodical analysis of perceptual constancies in the social field will be found in the recent monograph by Gustav Ichheiser (20). While we are in disagreement with minor parts in this treatment, it is generally supplementary to the basic thesis presented here.

have a bearing on the qualitative nature of this stereotype, it is modified but slowly (35). Thus we may generalize that a fundamental tendency of personality seemed to be one of perceiving constancy in individuals (or groups of individuals), and to behave toward them in terms of these perceived constancies.[4]

There is reason to believe (28, p. 107) that the preservation of a constant external environment is an aid to the development of a well-integrated ego. While we need not accept the analytic metaphor that "objects are internalized," we are on safe ground in stating that habits will function smoothly, and perceptual expectancies will be adequately related to objective reality, if this physical constancy is maintained.

The constancy of the social milieu is also important. The child establishes certain expectancies with regard to his parents—their personalities and behavior. He attains security as their actions fit into these expectancies. Furthermore, he imitates them, and develops certain expectancies for his own behavior patterned on theirs (the Freudian ego-ideal). Now, as Jacobson (21) and Plant (28) have noted, the effect of disappointment as regards their characteristics can be quite destructive of ego-integration, especially about the Oedipus age. It is worthy of note that both of these authors equate disappointment to disillusion. In our scheme this is equivalent to the disturbance of a perceptual constancy in the social field.

NEED AND PREFERENCE

Let us now turn to a criticism of homeostatic theory which is of considerable importance. This approach may be represented by P. T. Young (37), who has pointed out cogently that rats and humans may be motivated to more vigorous action by preference than by homeostatic need. The answer to this criticism can best be given in terms of perceptual phenomena.

We have already emphasized that the organism responds selectively to external stimuli when motivated by homeostatic tensions. Thus, certain perceived qualities of objects come to function as *cues* directing behavior toward these objects. It seems likely (1) that some such cues are innately given, in the sense that selective threshold differences are built into our nervous system. For example, mother's milk must be acceptable to the infant if the latter is to survive. We may therefore hypothesize that mammalian strains not provided with differential sensitivity to warm, sweet liquids were eliminated early in biological history. It is true, of course, that there are other substances which offer these cues (*cf.* Young's rats who chose saccharine solutions) but which are not homeostatic in character.

A realistic approach to behavior theory requires a consideration of the fact that modern conditions face the organism with new objects of indeterminate homeostatic significance. Man (presumably by Darwinian selection processes) is so biologically constituted that he has sensory mechanisms capable of reporting on most of the noxious stimuli having any considerable probability of occurrence in primitive life. Furthermore, these sensory selectivities are triggered to visceral tensions in such a way that violent activity is released by the perception of this cue (physical pain, for example).

Man has not, however, evolved sensory mechanisms for the detection of X-rays, gamma rays, and other noxious stimuli present in modern life. This does not constitute a criticism of homeostatic theory, but only a recognition of the fact that some new sources of tissue disequilibrium have been invented. Or-

[4] See Murphy (27, pp. 331–339) for a treatment of these phenomena in a rather different theoretical context.

ganic disturbances must set off behavioral activity by way of afferent fibers. When the sensory mechanism is inadequate to detect a harmful stimulus, no homeostatic protective action is possible.

Similarly, modern living presents us with many stimulus objects *perceived as identical* with those having homeostatic value. If these are preferred, though useless, it may mean an "error" on the part of the integrating mechanism; it does not invalidate the theory.

A further point merits consideration, namely the fact (2) that learning to identify objects as equilibrium-restoring is never mathematically perfect. The organism operates on a probability basis. In the language of hypothesis-learning, we may say something like this: "In the past, most warm, sweet liquids have served as tension-reducers. The probabilities are high that this warm, sweet liquid is also need-satisfying in character." The phenomena of stimulus equivalence and positive transfer suggest that, within certain limits of discrimination threshold, objects presenting similar cues will be perceived as identical. Thus rats and men may *prefer* substances which are not homeostatic in function, but are incorrectly identified as such.

Preference for foods may be changed either by satiating with the preferred food or by creating a need for the non-preferred substance (37). However, in the latter case it is necessary to break up the physically perceivable situation so that the preferred food does not affect the distance receptors simultaneously with the non-preferred. Otherwise the constancy based on former needs and tensions appears capable of blocking the establishment of a new habit adequate to the new need.

This seems to have considerable bearing on the success of reform or therapy. If the delinquent (or neurotic) is simply replaced in the environment which led him to develop maladjustive patterns of perceiving and acting, these are likely to be reinstated and to continue to dominate the motor system.

Young's own experiments (38) show conclusively that preferences can be built upon a homeostatic need. It thus appears far more defensible to hold that homeostasis is the primary motivational principle involved, and that preference (palatability, affectivity) is simply a derivative based upon (1) inherent sensitivity thresholds of homeostatic significance, or (2) non-discriminable differences from signs of homeostatic goal-objects.

At this point it will be well also to deal briefly with two less fundamental criticisms of homeostatic motivation theory. One of these calls attention to the fairly obvious fact that, in the short run at least, people often indulge in behavior which is disequilibrating; the other, that behavior directed to the maintenance of a constant state sometimes takes such a form as to prevent the achievement of that state. Neither of these objections seems to carry much weight.

The relationship between short-run disequilibrium and long-run equilibrium has been dealt with rather adequately by Freeman (14), following the excellent analysis by Freud (16). That men do in fact go on fasts, climb mountains, hunt dangerous animals and in other ways disturb constant states is a truism. That such behavior violates the principle of homeostasis is not a truism.

The organism is constantly faced with the necessity for maintaining a variety of constant states and hence with the task of determining priorities. It seems safe to assume that within the biological needs, the relative survival significance of a given demand is keyed to dominance of the motor system: that is, that the hierarchy of physiological

drives is a function of the threat to survival implied by a given deprivation. As we move from this level to the maintenance of a constant physical and a constant social environment, we encounter more difficulty in ascertaining the principles upon which dominance is based. It should be clear, nonetheless, that the organism in some way evolves standards of value, in terms of which choice is made as to the particular constancy which gets priority. Probably the history of the individual is decisive in this respect.

The facts indicate that the epithet "coward" may be more disturbing to equilibrium than the physical danger of facing a wild animal. Or, the humiliation of losing valued social status may be more upsetting than the physiological disequilibrium induced by mountain climbing. In terms of the view presented here, such choices will be functions of the perception of these alternatives, and this in turn will depend upon the number and kind of reinforcements related to such percepts. In one boy's family, physical prowess is constantly praised and rewarded; in another, it is ignored or depreciated. There is a significant relationship here to Freud's reality-principle; a short-run or minor disequilibrium may be accepted in order to achieve a long-run or major equilibrium. A fruitful approach to this problem is that of Mowrer (26), which utilizes the observation that some people orient their behavior to the rewards or punishments physically present or near in *time*, neglecting those to follow in the future. In the context of the present paper, the phenomenon is one of *perceiving as larger* that which is closer in time.

The second objection refers to those acts which ostensibly aim at restoring equilibrium but in fact prevent it. Thus we have the instance of the insecure, affection-starved woman who, in demanding love from people, so frightens them that she becomes even more insecure. When phrased thus, the problem promptly vanishes. No proponent of homeostatic theory has ever claimed that the organism did not make errors. Probably a young lion, trying to catch game, often is overeager and loses his dinner; this may be considered unfortunate—for him—but does not deny the applicability of homeostasis to his behavior.

This difference, of course, needs to be noted; the lion learns to correct his seeking behavior, or else he dies. The neurotic does not, without guidance, learn to identify and eliminate his errors; on the contrary, he is most likely to establish an artificial constancy, perhaps on a fantasy level, in which his acts are not errors. That such inherently unstable equilibria lead to a piling up of residual tension and so eventually to breakdown has been aptly stated by Freeman (14), as in a different context by all the psychoanalysts. Sex conflicts lead to neuroses, whereas conflicts about food do not, because an unstable equilibrium with regard to food-need results in the destruction of the organism. Perception of non-food objects as edible, and of food as inedible, means suicide. Such a perceptual constancy, as regards sex, may be extremely uncomfortable—and yet, as the patient sees it, more acceptable than the apparent alternative. It seems likely that neurotic equilibria become stabilized only with regard to conflicts which do not violate the most comprehensive constancy of all—the maintenance of the total organism as a going concern.

EGO-CONSTANCY AND EGO-MOTIVATION

Let us now return to the problem raised in an earlier passage, the problem of the dominance of social constancies over biological constancies. This is the problem raised by exceptions to the sug-

gestion made earlier, that biological demands finally control perception and behavior. How can homeostatic theory deal with the artist who starves in a garret to express his ideas, the martyr who prefers physical pain to an abandonment of his beliefs?

The solution to this problem seems to depend upon the evolution of a new perceptual object, the self or ego, and the establishment of a perceptual constancy with regard to it. The theory of the development of the ego as an object of perception has been presented adequately elsewhere (23, 2, 32). The tendency toward perceptual constancy will operate to hold constant the self-image. Since the ego will be repeatedly perceived as part of a total situation involving the restoration of biological equilibrium, physical constancy and social uniformity, it can become a highly-valued cue-object for the maintenance of all needed equilibria. The possibilities of mutual reinforcement (by different inner tensions) and of over-valuing the ego as object are therefore obvious.

FIG. 1. The inner tissue constancies are most resistant to disturbance, and mobilize maximum energy to restore equilibrium. The physical environment is maintained constant by perceptual and functional activities, as is the social environment. Individuals differ in the extent to which physical or social constancies will be defended.

FIG. 2. In some personalities, ego-constancies come to dominate the motor system even to the exclusion of biological constant states.

The maintenance of ego-constancy may involve physical, social or individual uniformities. The child may seek to maintain himself in relation to physical patterns of security or symbols of prestige, such as toys, clothing, etc.; or he may focus on dominance or submission, exhibitionism or withdrawal, as social patterns; or he may try to act out verbal labels attached to him by adults, such as studious, "bad boy," artistic, or stupid.

The self-image (including the relation of self to environment) so evolved represents a "constant state" which the organism seeks to preserve. As such it may dominate the motor system and may even prevent homeostatic action based on earlier physical or social constancies. The person defending his ego-system of percepts and values may accept social ostracism or even physical disequilibrium. The mature ego, therefore, has its own constancy function; it tends to render the personality more independent of random changes in the physical or social milieu.

In this connection it should (unfortunately, perhaps) be emphasized that only a modest percentage of people really come to value ego-constancy as highly as often-cited examples would suggest. Thus, we need only look at

Germany, where most people, even in the professional classes, abandoned valued portions of the self-image in order to preserve biological, physical and social constancies under the Nazi regime.

We suggest, however, that in some individuals a modification of the schema shown in Fig. 1 is necessary. For these persons the self or ego becomes a perceptual object, the constancy of which is highly valued. It may dominate over the social milieu, as when a person suffers ostracism for his ideals; or even over the physical environment, as in the man who indulges in hazardous activities for ego-gratification. Finally, in extreme forms, it may be represented as in Fig. 2, where the individual actually is more disturbed by loss of ego integrity than by hunger or pain.

The motivational potency of threats to the ego will depend, then, on the pattern of constancies an individual is trying to maintain, and upon their relative dominance. In everyday life this is likely to be ascertained by observing the types of disequilibrating stimuli which are most effective in mobilizing his energies. Thus we may find John (a viscerotonic, in Sheldon's schema) concerned mostly with his vegetative functions; he lives to eat, and is most profoundly disturbed by any stimulus which interferes with his visceral peace. Harry, on the other hand (perhaps an Adlerian case), may be concerned primarily with status equilibrium; his motivation is ego-centered, and any stimulus perceived as a threat to status sets off a violent reaction. Tom (studied by a Freudian, hence an anal-erotic) has an equilibrium based on order, scheduling and precision of physical arrangement; any interference with these patterns may be profoundly disturbing to him. Obviously, any number of such illustrations could be offered.

For the purposes of clinical personality study, it is more fruitful to investigate the particular *pattern of perceptual constancies* most characteristic of the person, rather than to hunt for behavioral constancies. Thus the orthodox analytic procedure is likely to determine father-figures, mother-figures, situations symbolizing traumatic (disequilibrating) stimuli, and so on. The non-directivists are concerned to obtain knowledge of the client's self-image, as well as his perception of reassuring and threatening social objects.

Action, of course, is directed by perception, not by the "physically real" stimulus. Under most conditions this is adaptive; it is, indeed, our justification for the survival value of the perceptual constancies. When the physically presented stimulus is so contrived as to give a perception of a radically different object (as in certain of the Ames demonstrations), behavior is governed by the percept, not by the intellectually known reality.

Clinical psychologists are, of course, familiar with this phenomenon. The patient perceives a harmless situation as involving a drastic threat to his ego. He may rationally know the threat to be non-existent; it may be demonstrated logically or even empirically to be non-threatening. Nevertheless, as long as the perception holds, the behavior is governed by perception, not by knowledge.

The importance of this point for social psychology was developed by Kurt Lewin (25) in a penetrating essay. Rational, intellectual education against prejudice, in favor of new ways of dealing with human-relations problems, is doomed to failure unless it is accompanied by education for a new way of perceiving the situation. If minority groups continue to be perceived as having undesirable characteristics, behavior toward them will be discriminatory. We may even say that, within this restricted

frame of reference, prejudice is rational; if the physically real minority group member had these traits, it would be proper to discriminate. The same, of course, can be said of the neurotic; a man would be a fool if he were not defensive when surrounded by the terrifying dangers which people the neurotic's environment. It is only by undermining the "unreal" perception that we can make progress.

In social relationships, behavioral constancy also reinforces perceptual constancy. If a man enters a group and perceives the other men as aggressive toward him, he will probably behave in such a way as to evoke aggression. A woman who attends a tea expecting to be snubbed may stay away from others and thus elicit non-accepting responses; she then concludes that her original perception of the situation was correct. There is, consequently, a major difference between the homeostatic process in the perception of physical and of social situations. Erroneous perceptions of physical constancies are automatically selfcorrecting; in the quest for need-gratification, behavior based on inadequate perceptions will fail of reinforcement. Because of the mechanism just sketched, behavior based on erroneous perceptions of social situations may be reinforced; thus an artificial constancy of the perceived environment is perpetuated.

According to the work of Frenkel-Brunswik (15) and her collaborators, intolerance of ambiguity is in itself a major personality variable. The secure individual is not seriously disturbed by unclear physical percepts or equivocal emotional relationships. Certain insecure personalities, on the other hand, seem to be quite upset by any deviation from clearly defined structures, either perceptual or emotional. This quest for security through rigidity may be a function of having change and uncertainty forced upon the child before he is mature enough, or the ego-system well enough organized, to accept them. Many neurotics are capable of normal functioning in a constant environment, but they are thrown into panic by even minor changes. Clearly, in these cases, ego-constancy has *not* been successfully developed to replace physical and social constancies.

PROJECTIVE TESTS

Projective tests reveal the inner personality to the extent that they expose perceptual constancies. If, in a series of Rorschach blots, the person repeatedly perceives objects in disturbed motion, or if he seems able to see only minute, carefully delineated forms, the clinician is provided with supposedly valuable information. When a series of TAT productions gives repeated characterizations of father-figures as stern, punishing and repressive, we feel that something of importance has been ascertained. The relative value of specific tests is largely a function of the extent to which they tap important percepts, particularly if the characteristics of these percepts are, for one or another reason, not available to conscious report.

Projective tests are more useful than reality situations for diagnostic purposes. The percept in the latter case is likely to be a compromise between a value corresponding to true "constancy" and that dictated by the physical stimulus.[8] Even the neurotic does not perceive all social situations as equally threatening. While his "constancy" hypothesis may be that all adult males are threatening, the smile, voice, etc., of a specific male acquaintance may give him some reassurance. The ambiguous projective situation thus gives a

[8] This happens also in the laboratory. *Cf.* particularly the studies cited by Woodworth (36, pp. 605–621).

more valid insight into this inner determinant of behavior than many reality situations.

THERAPY

The purpose of therapy, of course, is to help the patient achieve a realistic equilibrium in place of the unstable neurotic pattern he has evolved. Behavior aimed at the achievement of realistic need-gratifications and inner homeostasis is blocked by a pattern of inappropriate perceptual constancies. Therapy, then, must operate by modifying these perceptions of the self and the environment (*cf.* 33). Just as suggestion from a person of prestige may modify the perception of a social object (5), so suggestion from the respected therapist may induce modification of a perceived personal relationship. In the analytic situation, reactivation of infantile emotions without punishment and without rejection often leads to restructuring of percepts involved. This is not accomplished without extensive disturbances of equilibrium, and profound tensions within the patient.

As with projective tests, it is apparently possible in therapy (specifically, in the transference relationship) to evoke relatively "pure" emotions freed of reality factors. That is, if the therapist succeeds in keeping himself unclearly structured, the patient may project onto the therapist his image of one or more emotion-arousing figures; and the patient's experienced emotion in this case is uncomplicated by the reality features of the immediate situation. Since this makes an excellent opening for the therapist to demonstrate the projective character of the patient's perceptions, it offers an optimal chance for corrective work.

The modern trend in therapy calls for guided efforts at reality-testing by the patient (1, pp. 87–94). It is important that this be done if therapeutic gains are to transfer to everyday life, but it is futile to urge reality experimentation prior to insight and perceptual modification. Indeed, the neurotic at the onset of therapy will claim that he has tested reality and found it wanting. What he does not realize is that he never actually contacted reality; he perceived only his own projected universe of constant threats and frustrations. Thus a change in perception of the self and the environment is a necessary prelinminary to practice of new patterns.[6]

Implicit in the foregoing is the notion that therapy, in the early stages, leads to a disturbance of equilibrium. Neurosis is homeostatic in character; the neurotic has established his stable environment, with some dependable need-gratifications; even a painful symptom serves its purpose in the psychic economy. Phobias, compulsions, paralyses and other psychopathologies aid in the preservation of a precarious balance between gratification and threat.

If therapy is to be successful, this stable environment must be restructured. The patient immediately reacts to this as a threat, with consequences familiar to all clinicians. As Bergler (6) has noted, "what neurotics fear most" is a

[6] It is perhaps worth noting that the same symptomatic pattern of constancies can be produced by quite divergent series of events. Let us consider (a) a young woman who felt rejected by her parents, although she was in fact physically secure; who developed a fantasy of being orphaned, of being punished for some mysterious but enormous guilt; and who in consequence perceived herself as inadequate and worthless. Contrast (b) a young woman who was in fact orphaned, treated brutally by a family with whom she was placed, and indoctrinated with feelings of sin and guilt in a religious orphanage. The perceptual constancies which characterize the two personalities may be superficially quite similar; but in case (b) they have been reinforced so much more regularly and intensely that the therapeutic task is vastly harder. Even years of life under relatively secure economic and domestic conditions may fail to modify these constancies.

disturbance of this formula, or "basic fallacy," which we have shown to be a form of perceptual constancy. It should not be surprising, furthermore, if modes of perceiving practiced for twenty or thirty years cannot be modified overnight.

Motivation is necessary if this restructuring is to be achieved. A person comes for therapy only when he is aware of a discrepancy between the equilibrium he has attained and that formerly possessed, or that believed to be attainable. There is nothing about the concept of homeostasis that is defeatist in character. While it is true that some pathological equilibria seem so stable as to defy therapeutic intervention (schizophrenias), it is generally possible to set up for the patient a fantasied new situation with a more favorable balance than he has achieved. Such phenomena as the positive transference can be utilized to provide some gratification, counterbalancing the painful effects of disequilibration as therapy proceeds. As therapy approaches its conclusion, many patients also show symptoms of disturbance as this new equilibrium must in turn be abandoned. Only the presence of these motivational factors makes possible the therapeutic modification of perceptions; the neuromuscular system is subservient to the vegetative system.

SUMMARY

Homeostasis is accepted as a general biological law. Since personality is developed on a biological foundation, it must follow homeostatic principles to some extent. Actually, these principles recur in many aspects of the psychology of personality.

Considering personality as a universal, we find the maintenance of constant states not only at the microscopic level (tissue conditions) but also at macroscopic levels (objects in the physical environment, and persons in the social environment). Physical and social constancies are shown to function in the service of tissue constancies. Disturbances at these macroscopic levels set off vigorous energy mobilizations comparable with those induced by disequilibrium on the tissue level. Constancies may be perceptual (uniform percept with varying "real" stimuli) or functional (manipulation of the "real" environment to reduce variation).

With reference to personality as a unique individual phenomenon, it is suggested that the homeostatic approach is useful in several ways. (1) The personality is characterized by the particular equilibria, disturbance of which gives rise to maximum energy mobilization, and by the particular perceptual constancies, especially social and ego constancies, which have been developed. (2) Neurotic, unrealistic equilibria can develop with reference to needs not directly involved in organismic survival, *e.g.*, sex. Such unrealistic equilibria involve perceptual constancies not appropriate to the "real" situation, but often reinforced because resultant behavior seems to lead to confirmation of the constancy hypothesis. (3) Projective tests may give a more adequate picture of these constancies than would result from observation in "real" situations. (4) Therapy involves disturbing the neurotic equilibrium, restructuring the unrealistic percepts, and evolving a new equilibrium providing more need-gratification.

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THEORY OF DOUBLE, TRIPLE, AND QUADRUPLE REPETITION [1]

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INTRODUCTION

One of the appropriate tests of the adequacy of a theoretical system is its ability to mediate the rigorous derivation of the results of an experiment, utilizing nothing but the principles of the system in question together with the conditions operating in the experiment. Such a procedure may actually test two aspects of a system: its completeness and its validity. A system, no matter how complex and detailed, cannot be considered *complete* if it does not permit a derivation to be made wherein each step is dictated by the theoretical principles themselves, and nothing is left to the "interpretative skill" of the individual who performs the derivation. There can, of course, be no real test of *validity* unless the results of such a derivation can be compared with empirical fact.

The aim of this report is to present the application of this point of view to Hull's general theoretical system (3, 8) as it relates to an experiment on double, triple, and quadruple repetition learning (14). The writer has here explored in some detail, although by no means exhaustively, the possibilities of rigorous derivation of certain of the results of this experiment from hypotheses advanced by Hull. It should be emphasized that this is not primarily an attempt to test the correctness of the hypotheses through submitting their implications to experimental test. Rather, it constitutes an attempt to determine, by a process of explicit derivation, the extent to which the theory is sufficiently complete to deal with the type of situation involved.

In another sense, since the writer at times used a frankly trial-and-error approach in deciding upon the values of particular constants to use in certain of the equations, this may be regarded as an inductive attempt to provide, for this particular experimental situation, what Koch and Daniel (10) would call "content" for the hypothetico-deductive system formulated by Hull.

In the experiment here being considered, rats were trained in a linear alley maze in which each choice-point comprised two doors through one of which the rat might push. Three groups of thirty rats each were trained on four, six, and eight units of the maze, respectively. The sequences of correct choice, imposed by blocking the incorrect doors, were as follows:

Maze 1: *AABB*
Maze 2: *AAABBB*
Maze 3: *AAAABBBB*

where "*A*" may represent either right or left, and "*B*," the opposite. All animals were given fifty trials, one per day, under approximately twenty-two hours' hunger drive, with food reward at the end of the maze. During both the preliminary habituation and the experimental training the units of the maze were interchanged, and the whole maze was

[1] This article is based upon a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Graduate School of Yale University. The writer wishes to express his deep gratitude to Professor Clark L. Hull, under whose supervision the study was carried out. The work herein reported is part of the coordinated research program of the Institute of Human Relations, Yale University.

rotated between successive trials in order to eliminate any consistent external cues which might provide a basis for discrimination among the various choice-points.

The results of the experiment which are of primary interest to us are shown in Fig. 1A. Because the number of relationships among even these limited aspects of the data is so large, it has been necessary to select certain of them to be dealt with in detail in working out the derivation presented below. The empirical facts which it has been the goal of the present study to derive within the framework of learning theory are as follows:

1. The point of maximum difficulty falls at the last *A* choice-point in all three mazes.

2. At an advanced stage of learning, a convex gradient of frequency of correct choice extends in both directions from the last *A* choice-point.

3. This gradient is asymmetrical, being slightly higher for the last half of each maze than for the first.

4. Accuracy approaches 100 per cent at the first and last choice-points, perhaps somewhat more closely at the last than at the first.

5. The last two choice-points in Maze 2, and the last three in Maze 3, show approximately equal frequencies of correct choice late in training.

6. When the midpoint of each maze is taken as the reference point, the difficulty of corresponding choice-points is, in general, positively related to the length of the maze. (*E.g.*, choice-point III in Maze 3 is more difficult than the corresponding choice-point II in Maze 2.)

THEORETICAL ANALYSIS AND DERIVATION

A preliminary analysis of this learning situation from the standpoint of learning theory indicates the following:[2]

1. The proportion of correct choices at each choice-point is a normal probability function of the difference in strength of the right-turning and left-turning tendencies at that choice-point (3, 8).

2. The strength of each habit at any particular choice-point is, in turn, a function of the following:

(a) the number of times the response has occurred at that choice-point, with subsequent reinforcement (3, p. 178);

[2] Hull's theory includes a number of other principles, which have not been utilized in the present derivation. (One could say with equal accuracy that they have been assigned a weight of zero.) These include:

1. *Response generalization* (3, p. 267 ff.): It is a reasonable supposition that reinforcement of the right-turning response also strengthens, to some extent, the left-turning response—*i.e.*, that both responses are members of a single habit-family. If such generalization were 100% there could be no learning of the response sequence. Assumptions about the actual amount of such generalization would make no important difference in the derived relationships among the choice-points, since the different choice-points and the different mazes were all alike with respect to the responses involved. Accordingly, this principle was not utilized in the present derivations.

2. *Reactive inhibition* (3, p. 277 ff.): Distribution of trials at twenty-four hour intervals may be assumed to have allowed inhibitory effects resulting from mere performance of responses to dissipate between trials, precluding any important cumulative effects. This principle, therefore, appears to have little if any significance for the present experiment.

3. *Conditioned inhibition* (3, p. 282 ff.): Although errors must be assumed to generate conditioned inhibition in this situation, such conditioned inhibition would be inversely proportional to the number of correct responses at each choice-point. The omission of this principle would not, therefore, distort seriously the relationships among the empirical data listed above, although it would presumably affect the absolute numerical quantities involved. Its inclusion in the derivations, on the other hand, would greatly increase the already considerable computational labor involved.

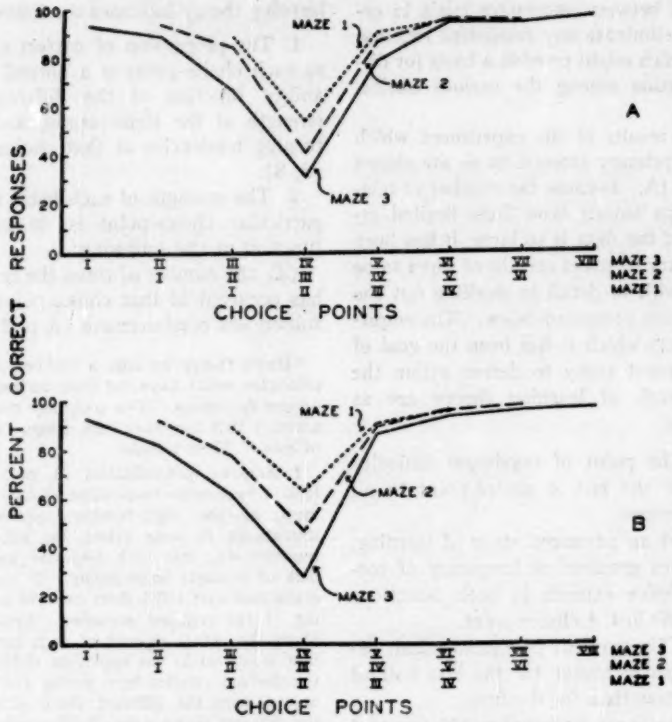

FIG. 1. A. The empirical gradients of correct choice in the three mazes, on trials 41–50. B. The theoretical gradients of correct choice, as derived in the text. For ease of comparison, the point of maximum difficulty is placed at the same position for all three mazes in both figures.

(b) the immediacy with which reinforcement has followed the performance of the responses, and hence (1) the distance of the choice-point from the goal, and (2) the magnitude of secondary reinforcement which follows the response (3, p. 98);

(c) the generalization to that choice-point of homologous response tendencies generated at other choice-points, *i.e.*, stimulus generalization (3, p. 199). This in turn is a function of (1) the similarity between the stimulus complexes at the choice-point in question and at each other choice-point where the response may have been reinforced, and (2) the strength of the homologous tendencies at each such choice-point.

The actual course of derivation is approximately the reverse of the above statements, and involves the following steps:

1. Determination of quantitative values to represent the "original" or ungeneralized habit strengths at each choice-point in each maze at the late stage of training represented by trials 41–50. This involves assumptions concerning:

(a) the strength of a habit with no delay of reinforcement, under these conditions;

(b) the length of time by which each response in the maze is separated from primary reinforcement at the goal;

(c) the form of the gradient of primary reinforcement;

(d) the role of secondary reinforcement in this situation.

2. Determination of the degree to which each habit (*i.e.*, the habit reinforced at each choice-point) generalizes to each other choice-point.

This involves supplementary assumptions concerning

(a) the similarity between the stimulus complexes at each pair of choice-points;

(b) the characteristics of the gradients of anticipatory and perseverative generalization.

3. Summation of the homologous response tendencies at each choice-point.

4. Determination, by subtraction, of the amount by which the stronger summated tendency exceeds the weaker, at each choice-point.

5. Determination of the resulting proportion of right and wrong responses, at each choice-point.

Because of space limitations, the step by step derivation is presented here only for the six-unit maze; calculations for the four- and eight-unit mazes are exactly comparable, however, except for the number of units involved.

The first step is the calculation of the original or ungeneralized habit strengths at each choice-point. For this, it is assumed that one second elapses between successive correct responses, and that the goal gradient in this situation is represented by the following equation:

$$H' = H \times 10^{-jt} \qquad (1)$$

where: H' is the strength of a habit established with a delay of reinforcement of t seconds;

H is the strength of a habit established under the same conditions of drive, reward, etc., with immediate reward (*i.e.*, where $t = 0$). This is here set at 50;

j is an arithmetical constant,[3] here set at .004;

t is the time in seconds between the performance of a response and the occurrence of primary reinforcement.

When values of 1, 2, 3, 4, 5, and 6, corresponding to the delay of reinforcement in units VI, V, IV, III, II, and I, respectively, are substituted for t in Equation 1, the values shown in Table I are obtained, representing the ungeneralized habit strengths in the several choice-points of the six-unit maze.

TABLE I

THE STRENGTHS OF THE UNGENERALIZED HABITS IN EACH UNIT OF THE SIX UNIT MAZE

Unit	t	H'
I	6″	47.31
II	5″	47.75
III	4″	48.19
IV	3″	48.63
V	2″	49.08
VI	1″	49.54

The next step is to compute the strength with which the habit established at each choice-point will generalize to each other unit. This involves as a first step the determination of the degree of stimulus similarity or difference between each unit and all the others.

Inasmuch as differences in external stimulation at the several choice-points were eliminated through rotation and interchange, the only differences must have depended in some way upon internal

[3] It will be noted that this value for j yields a very flat, practically horizontal "gradient." This is what might be expected if there were a substantial amount of secondary reinforcement associated with *each* response, as would presumably result in our experiment from the preliminary training in the maze. *Cf.* the discussions of Spence (12), Perkins (11), and Grice (1), and Hull's discussion of the effects of serial as compared with terminal reinforcement (5, 6).

processes within the animals. Two types of such processes may be hypothesized: (1) a process, here designated as s_p, which changes as a monotonic function of distance from the starting point—such as a decaying trace of stimulation resulting from handling the animal and placing him in the maze, or an increasing tension resulting from the continuous running activity itself; and (2) traces produced specifically by the choice-responses themselves, a new one arising as each response is made; these are designated as s_A and s_B, corresponding to choices in the *A* and *B* directions.

In the present derivation both types of process are assumed, since there seem to be no grounds on which to deny categorically the existence of either. It is further assumed that the trace produced by one right-turning response is qualitatively identical with that produced by any other: two right-turning traces are assumed to differ only in strength, the older being of course the weaker.

A further point of importance is that the traces from a right turn and from a left turn may be conceived as quite similar or as quite different. Presumably they would not be completely identical, but they might be very much alike, since the responses are bilaterally symmetrical and involve similar postural and locomotor elements. In working out this derivation it was found that a satisfactory agreement with empirical results was secured when complete homogeneity of these traces was assumed. The results of the alternative assumption of heterogeneity are shown below (Fig. 2). It may also be pointed out that these two types of trace, s_p and $s_{A,\,B}$, are assumed to provide the *only* basis for differential responses in the various choice-points, and hence for the regular response sequences which appeared.

At each choice-point, then, there is assumed to be a unique combination of traces. To give quantitative expression to this, it is assumed that:

$$s = S \times 10^{-it} \qquad (2)$$

where: s is the strength of a trace t seconds after the termination of the events which initiated it;

S is the strength of the trace at the moment of termination of the events which initiated it. This is here set at 25, both for the trace s_p and for the traces s_A and s_B;

i is a constant, here set at .10;

t is the time in seconds since the termination of the events which initiated the trace.

When the appropriate values for t are substituted in Equation 2, there result the values shown in Table II, representing the strengths of the several traces at the time of response in each choice-point.

Since the traces represented in Table II are presumably physiological processes, the appropriate method for combining those of similar origin is the Hull-Day summation formula (3, p. 200) which provides for a limit (here assumed to be 100) which the total process may

TABLE II

THE STRENGTHS OF THE TRACES AT THE TIME OF RESPONSE IN EACH CHOICE-POINT

Roman numeral subscripts indicate the unit or choice-point in which the response initiating a given trace occurred.

Traces	Choice-Points					
	I	II	III	IV	V	VI
s_p	19.86	15.77	12.53	9.95	7.91	6.28
s_{A_I}	—	19.86	15.77	12.53	9.95	7.91
$s_{A_{II}}$	—	—	19.86	15.77	12.53	9.95
$s_{A_{III}}$	—	—	—	19.86	15.77	12.53
$s_{B_{IV}}$	—	—	—	—	19.86	15.77
s_{B_V}	—	—	—	—	—	19.86

approach as increments are added, although the effect of adding an increment of a given size is a negative function of the strength of the process already developed. In the present case, since it is explicitly assumed that the traces of right-turning and left-turning are qualitatively alike, all of the *A* and *B* traces at any one choice-point are summated together without differentiation, and the symbol $s_{A,B}$ is used to represent a trace-aggregate which may include both *A* and *B* traces. (In the derivation whose results are shown in Fig. 2, on the other hand, the *A* and *B* traces were summated separately, since it was there assumed that they were qualitatively dissimilar or heterogeneous.) The results of this summation under the present assumptions are shown in Table III.

It is assumed that except for the traces and trace aggregates, the stimulus compounds in the various units are identical. So far as external stimuli are concerned, then, generalization of habits from each choice-point to each other one should occur without any decrement, *i.e.*, with 100 per cent of their original strength. Conversely, it is only as the stimulus aggregates differ, as described in Table III, that generalization should fail to occur. The strength of a generalized habit, then, will be a negative function of the difference between the stimulus aggregate to which it was conditioned, and the one by which it is being evoked.

TABLE III

THE STRENGTHS OF THE TRACE s_p AND OF THE AGGREGATE OF TRACES s_A AND s_B, AT THE TIME OF RESPONSE IN EACH CHOICE-POINT

Traces	Choice-Points					
	I	II	III	IV	V	VI
s_p	19.86	15.77	12.53	9.95	7.91	6.28
$s_{A,B}$	0.00	19.86	32.50	40.96	46.83	51.04

TABLE IV

THE *d* VALUES REPRESENTING THE DIFFERENCE BETWEEN EVERY PAIR OF CHOICE-POINTS, AS DERIVED FROM TABLE III

Choice-Points	Choice-Points					
	I	II	III	IV	V	VI
I	0.00	23.95	38.83	50.87	58.78	64.62
II	23.95	0.00	15.88	26.92	34.83	40.67
III	38.83	15.88	0.00	11.04	18.95	24.79
IV	50.87	26.92	11.04	0.00	7.91	13.75
V	58.78	34.83	18.95	7.91	0.00	5.84
VI	64.62	40.67	24.79	13.75	5.84	0.00

Such differences between stimulus aggregates are here designated by the letter *d*. While many different relationships might be hypothesized between the numerical differences which may be derived from Table III and the construct *d* which enters into the generalization equation, it is here assumed, most simply, that they are equal. Table IV was derived from Table III, then, by adding together, for each pair of choice-points, the amounts by which the two choice-points differ in the strength of each trace.[4] Thus, for example, in column 3, row 2, the value of 15.88 by which choice-points II and III differ is the sum of their difference with respect to trace s_p ($15.77 - 12.53 = 3.24$) and their difference with respect to the trace aggregate $s_{A,B}$ ($32.50 - 19.86 = 12.64$).

Having thus determined the relative differences between every pair of choice-points, it is necessary to take the habit strength which exists at each (as shown in Table I) and compute the degree to which it generalizes to every other choice-point. Generalization is calcu-

[4] This arithmetical addition of trace strengths could, of course, be replaced by some sort of multiplicative relationship, corresponding to Hull's hypothesis of afferent neural interaction (3, p. 47), if any basis could be found for making a specific assumption concerning such a relationship.

lated from the following equation (3, p. 199):

$$\bar{H} = H' \times 10^{-kd} \qquad (3)$$

where: $\bar{H}$ is the generalized habit strength;

H' is the original habit strength (as determined from Equation 1 and shown in Table I);

k is a constant, here assigned a value of .01 for anticipatory generalization and .015 for perseverative generalization; [5]

d is the difference between the choice-points involved, as shown in Table IV.

When the appropriate values are substituted in Equation 3, the generalized habit strengths shown in Table V are obtained. This table is to be read as showing generalization *from* the units shown at the left *toward* those shown at the top. Thus the habit generalizing from Unit I to Unit III is shown in the third column in row 1 to have a strength of 11.96; that generalizing back from Unit III to Unit I is shown in the third row of the first column, with a value of 19.26. Thus the upper-right diagonal half of the table shows the values for perseverative generalization, the lower-left half, for anticipatory. The diagonal values in heavy type are, of course, the original or ungeneralized habit strengths.

[5] The assumption of a difference in the steepness of anticipatory and perseverative generalization gradients corresponds to the empirical findings reported by Hull and others in a series of experiments utilizing a rather similar type of maze (2, 5, 13). It may also be derivable on a theoretical basis from Hull's recent hypothesis of stimulus intensity dynamism (7), taken in conjunction with the presumptive intensity gradients of the traces to which the choice reactions are cued. Since the later responses in the series are cued to traces which are, individually, weaker at the time of the later responses than at the time of earlier responses, we should expect that generalization based on these traces would be stronger in the case of anticipatory generalization than for perseverative, since in anticipatory generalization the stimulus (trace) evoking the generalized habit is stronger or more intense than the trace evoking the ungeneralized habit, while in the case of perseverative generalization the reverse is true.

TABLE V

THE STRENGTHS OF HABITS WHICH GENERALIZE FROM EACH UNIT TO EACH OTHER UNIT (SEE TEXT)

Units at which the generalized habit originates	Units to which habits generalize					
	I	II	III	IV	V	VI
I	**47.31**	20.69	11.96	8.17	6.21	.96
II	27.51	**47.75**	27.59	18.84	14.34	11.72
III	19.26	33.43	**48.19**	32.91	25.05	20.47
IV	15.08	26.16	37.71	**48.63**	37.01	30.25
V	12.68	22.01	31.73	40.91	**49.08**	40.11
VI	11.19	19.42	28.00	36.09	43.31	**49.54**

In order to find the total strength of each response tendency at each choice-point, the habit strengths in Table V are now summated, again by means of the Hull-Day formula. Since the habits which originate at the choice-points in the first half of the maze (shown in the first three rows of Table V) mediate the *A* reaction, these are summated together, as are the habit strengths originating in the last half of the maze, mediating the *B* reaction. The final reaction probability at each choice-point is a function of the difference in the strengths of these two conflicting reaction tendencies. The total strengths of the *A* and *B* tendencies at each choice-

TABLE VI

THE TOTAL (SUMMATED) STRENGTHS OF THE *A* AND *B* TENDENCIES AT EACH CHOICE-POINT

	Choice-Points					
	I	II	III	IV	V	VI
A tendency	69.17	72.41	66.97	50.00	39.78	30.46
B tendency	34.14	53.60	69.38	80.60	81.82	78.92

TABLE VII

Row 1 shows the amount by which the correct habit predominates at each choice-point; in Row 2 this is shown as a standard score based on a standard deviation of 25; Row 3 shows the corresponding per cent of correct reactions.

	Choice-Points					
	I	II	III	IV	V	VI
(1)	35.03	18.81	−2.41	30.60	42.04	48.46
(2)	1.40	.75	−.10	1.22	1.68	1.94
(3)	91.92	77.34	46.02	88.88	95.35	97.38

point, as obtained by the above summation, are shown in Table VI.

Our next step, the calculation of the expected frequency of correct choice from the values in Table VI, depends on the hypothesis of continuous oscillation of habit strengths (3, p. 304 ff.; 8). As stated above, the proportion of correct responses at any choice-point is presumed to be a normal probability function of the difference in strength of the two competing habits, right-turning and left-turning. Accordingly, the difference between the total A and B habit strengths shown in Table VI is obtained by subtraction; these values, representing the preponderance of the "right" habit over the "wrong" at each choice-point, appear as the first row in Table VII. Next, each of these "net" habit strengths is divided by 25, the assumed standard deviation of the distribution of momentary habit strengths; [6] the resulting values, representing the preponderance of the "right" habit over the "wrong" in standard score units, appear in the second row of Table VII. Finally, the percentage of occasions on which the correct habit will actually dominate, despite the momentary fluctuations of both habits, and consequently the percentage of occasions on which the correct response would actually emerge, is read off directly from a normal probability table. These percentages are shown in the last row of Table VII.

This completes the derivation itself. The results of this derivation, for the three lengths of maze used, are shown in Fig. 1B, which may be compared directly with Fig. 1A. Such comparison shows a reasonably good agreement and, particularly, reveals that all six of the principal features of the empirical data listed above (p. 19) are revealed by the theoretical gradients as well. We may therefore conclude that the procedures of derivation, and therefore the hypotheses upon which the derivation was based, are at least fairly well suited to the particular maze learning situation here considered.

We might also be tempted to conclude that the theory is therefore "complete" in the sense of being able to mediate a rigorous deduction for this situation. Such a conclusion would be completely justified, however, only if all of the constants employed, as well as the forms of the equations used, were specifically dictated by the theory. This was not the case. The original ungeneralized habit strength with zero delay of reinforcement, for example, was set at 50, without reference to the theory; similarly, the standard deviation of the oscillation distribution was set at 25, although there was no rigorous theoretical basis for this particular value. It is therefore necessary to conclude that, while the theoretical system *provides for* such a situation as this, it is not mathematically complete with respect to the constants to be employed in the derivation of results in specific situations. As Hull has pointed out (3, 4), the deter-

[6] This particular numerical assumption is one which cannot, so far as the writer is aware, be logically justified on theoretical grounds alone; indeed, the whole problem of oscillation is in need of much more intensive analysis than it has yet received. The fact that this rather large value "works" may provide some indication of the relative range of oscillation in such situations as this, however.

mination of such constants is at the same time one of the most important and one of the most difficult tasks of theory construction.

ALTERNATIVE ASSUMPTIONS

Although a number of our quantitative assumptions cannot be derived from theoretical premises, it is possible to demonstrate their usefulness, within the framework of the theoretical system, by comparing the results of the above derivation with the results of analogous derivations in which different constants are employed. A number of such derivations are described below.

One of the most debatable of the assumptions in the above derivation, perhaps, is that of the absolute homogeneity of the traces produced by right-turning and left-turning responses. Such an assumption of homogeneity, as we have seen, yields a reasonably correct set of derived frequencies of correct choice. By contrast, when it is assumed that the A and B traces are completely dissimilar, the resulting derived frequencies of correct choice diverge seriously from empirical fact, as Fig. 2 shows. The gradients are too flat, and, most strikingly, the gradient for the second half of the eight-unit maze has a sigmoid shape, rather than the monotonic form which resulted from the assumption of homogeneity of traces, and which characterized the empirical results. We must conclude, therefore, that within the present framework there is no justification for assuming that these traces are completely heterogeneous.

This does not, of course, rule out the possibility of *partial* homogeneity. This would, indeed, correspond more closely than does our assumption of complete homogeneity to the presumptive nature of the *A* and *B* responses, since they possess in common many elements such as forward locomotion, leg movements, etc. They differ only with respect to the particular turns involved, and even in this respect they are more alike than might at first appear, because when a rat turns right to pass through a door he must immediately turn left again to return to the center of the alley, and vice versa. Thus a "right-turning" response actually involves a right-left sequence of turns, while a "left-turning" response involves a left-right sequence. The optimal assumption, therefore, might be

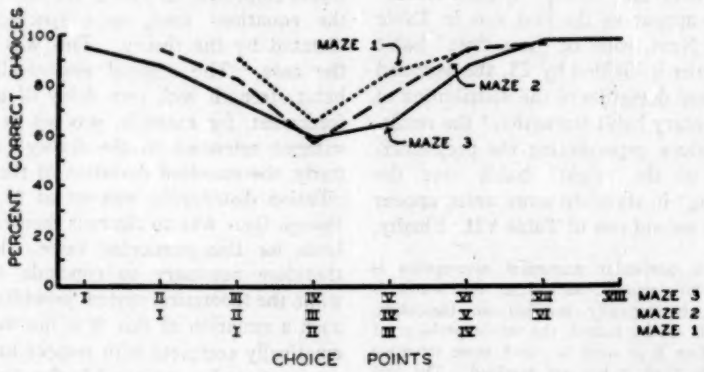

FIG. 2. The theoretical gradients of correct choice when it is assumed that the response-produced traces s_A and s_B are heterogeneous and enter independently into the stimulus aggregates at the several choice-points.

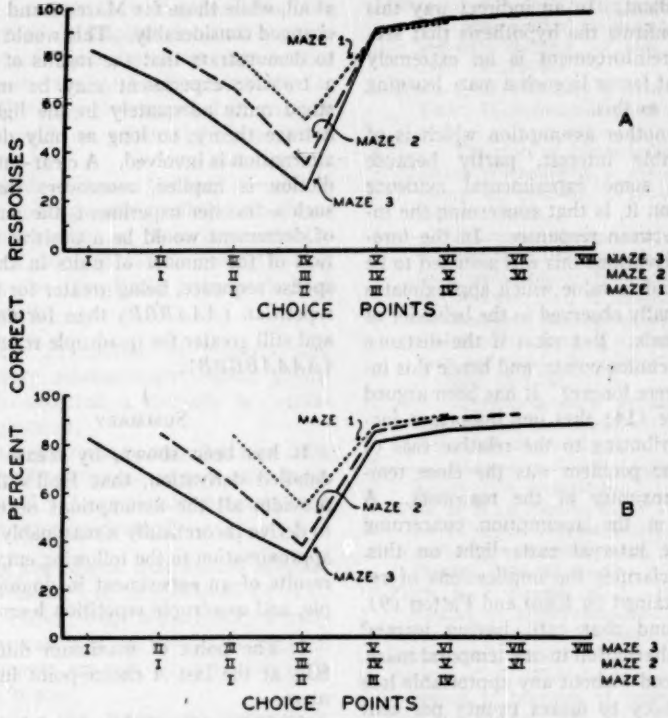

FIG. 3. A. The theoretical gradients of correct choice when the exponential constant j in the goal gradient equation is changed from .004 to .03.

B. The theoretical gradients of correct choice when the interval between successive correct responses is assumed to be 2 seconds instead of 1 second.

that some eighty or ninety per cent of the trace strengths involved should be considered as homogeneous, the other ten or twenty per cent being treated as heterogeneous and summated separately.

A second assumption in our original derivation which might appear to be open to question is that of a virtually flat, horizontal goal gradient resulting, presumably, from the summation of primary and secondary reinforcement effects, and entering the mathematical derivation as the value of .004 of the exponent j in Equation 1. As a partial test of this assumption, this value was changed to .03, and the derivation repeated, all other values remaining the same. The results of this derivation are shown in Fig. 3A. Comparison of the gradients here with those of our first derivation (Fig. 1B) shows that the assumption of a steeper goal gradient has resulted in a lowering of the gradients in the first half of the maze and has, in addition, distorted the relationship among the mazes at the first B choice-point, making the theoretical frequencies of correct choice exactly equal for Mazes 2 and 3, and somewhat lower for Maze 1. This of course runs counter to empirical fact, and constitutes another reason for rejecting the assumption of a steeper

goal gradient. In an indirect way this result confirms the hypothesis that secondary reinforcement is an extremely important factor in such a maze learning situation as this.

Still another assumption which is of considerable interest, partly because there is some experimental evidence bearing on it, is that concerning the interval between responses. In the foregoing derivations this was assumed to be one second, a value which approximates that actually observed in the behavior of the animals. But what if the distance between choice-points, and hence this interval, were longer? It has been argued elsewhere (14) that one important factor contributing to the relative ease of this maze problem was the close temporal proximity of the responses. A change in the assumption concerning the time interval casts light on this. It also clarifies the implications of results obtained by Karn and Patton (9), who found that cats, having learned double alternation in one temporal maze, generalized without any appreciable loss of accuracy to mazes twenty per cent larger and smaller. They argued that "retained effects" (*i.e.*, response-produced traces) could not mediate such a transfer, and concluded that some sort of symbolic process must have been operating. By changing our assumption concerning the time interval between responses we may make our derivation conform to their experimental operations, and see whether our "retained effects" hypothesis would predict a loss of the habits under such changed conditions.

The results of such a derivation, in which the interval between responses was increased by 100 per cent, thus becoming two seconds in place of the one second assumed earlier, are shown in Fig. 3B. Here it will be noted that the gradient for Maze 1 is changed hardly at all, while those for Mazes 2 and 3 are changed considerably. This would seem to demonstrate that the results of such a transfer experiment may be understood quite adequately in the light of a trace theory, so long as only double alternation is involved. A clear-cut prediction is implied, moreover: that in such a transfer experiment, the amount of decrement would be a positive function of the number of units in the response sequence, being greater for triple repetition (*AAABBB*) than for double, and still greater for quadruple repetition (*AAAABBBB*).

SUMMARY

It has been shown, by means of a detailed derivation, that Hull's theory provides all the assumptions necessary to derive theoretically a reasonably close approximation to the following empirical results of an experiment in double, triple, and quadruple repetition learning:

1. The point of maximum difficulty falls at the last *A* choice-point in each maze.
2. At an advanced stage of learning, a convex gradient of frequency of correct choices extends in both directions from the last *A* choice-point.
3. This gradient is asymmetrical, being slightly higher for the last half of each maze than for the first.
4. Accuracy approaches one hundred per cent at the first and last choice-points, somewhat more closely at the last than at the first.
5. The last two choice-points in Maze 2 (*AAABBB*) and the last three in Maze 3 (*AAAABBBB*) show approximately equal frequencies of correct choice late in training.
6. When the midpoint of each maze is taken as the reference point, the difficulty of corresponding choice-points is, in general, positively related to the length of the maze.

At the same time, it appears that the theory is incomplete in that the arithmetical values of a number of the constants employed are not formally included within the system, but must be determined on other than theoretical grounds.

The discrepancies between theoretical and empirical error-gradients which result when some of these constants are changed suggest rather strongly that within the theoretical framework here employed:

1. the summation of primary and secondary reinforcement effects yields, in this situation, a virtually horizontal goal gradient;

2. the response-produced traces from right and left turns are to a very large degree, if not completely, homogeneous or functionally identical.

It is also shown that double alternation behavior can be explained by (*i.e.*, derived from) what is essentially a trace theory, and that the results of transfer experiments are not incompatible with such a theory.

Finally, the theoretical derivations yielded a clear-cut prediction: that the amount of disruption of the serial response habit in a transfer experiment involving a longer interval between responses would be a positive function of the number of units in the sequence.

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THE CONCEPT OF ENERGY MOBILIZATION [1]

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The concept of "energy mobilization" has been employed in several papers in which I have suggested the revision of certain traditional descriptive categories of psychology (13, 14, 15, 17). These expressions of dissatisfaction with the existing concepts of psychology were examples of an attitude which was widely shared. Lyle Lanier, for instance, said in 1937: "Recent years have witnessed a growing dissatisfaction on the part of psychologists with the systematic analysis of psychological events represented by the traditional categories" (27).

In the papers to which I have referred, I argued that the phenomena described by certain of our psychological concepts could be fully described by means of a smaller number of more basic categories (15, 17). The descriptive categories suggested were (1) direction, and (2) energy mobilization.[2] I expressed the opinion that all behavior shows variation in goal-direction and in intensity, or energy mobilization, and apparently in *only* these two basic dimensions. I suggested that, by making use of these two concepts, we should both simplify psychological description and also, in many instances, avoid the present practice of looking for different correlates of similar phenomena placed by our present concepts in different categories. In none of these papers, however, has the concept of energy mobilization been fully elaborated, in either its theoretical implications or its justification by experimental evidence. The present paper, therefore, will concern itself with the further elaboration of this concept, though a full discussion of the topic must await the completion of a manuscript now in preparation.

The assumption that the release of energy is a significant aspect of behavior is by no means a new one. In fact, psychological theories of almost every type have incorporated the notion of some dynamic force or forces in behavior. Such forces have been variously referred to as "instincts," "drives," "urges," "tensions," "motives," "emotions," or "libido." In every instance the assumption has been made that *energy* was released. However, there has been a notable tendency to assume that the energy released was, in a sense, specific to the channel of release, or at any rate to incorporate in a single concept, such as that of motive, both the *direction* taken by the behavior and the degree of *energy mobilization* shown by the response. For example, a motive is said both to *energize* behavior and to *direct* it. Any one of the excited emotions, such as anger or fear, is said to *energize* behavior and also to determine the *direction* it will take. Similarly, the older concept of instincts, as well as the newer one of drives, incorporates the idea of *energy's* being *released* and *guided* in a particular direction. Freud's libido is a particular kind of *energy* which seeks release in certain *channels* or *directions*,

[1] Read as the presidential address at the Forty-second Annual Meeting of the Southern Society for Philosophy and Psychology, April 7, 1950.

[2] The term "energy mobilization" means nothing different from energy release within the organism, or the conversion of potential energy to kinetic energy. The term "mobilization" rather than "release" was employed to avoid the suggestion that the energy released was necessarily expended in action upon the external environment.

but which may be diverted with respect to its channel of release. Lewin's "tensions" appear to be states of greater energy mobilization which are tied to some particular motivating condition which gives direction to their expression.[3]

In every instance the dynamics of behavior is described by a concept which incorporates both the *direction* of the behavior and the *energy level* of the behavior. And yet these two aspects of behavior may *vary independently* of each other, though not of course independently of the organism and its goals. A single concept which incorporates *both* of these separate aspects of behavior is one which will hardly lead to the best results in scientific investigation. For example, in studies of the emotions it has frequently been the aim of the investigator to discover whether a certain factor, such as the administration of adrenalin, would produce an emotion, or whether another factor, such as the removal of the cerebral cortex, would prevent an emotion from occurring. But emotion, as described by our present concept, is not a unitary thing. It has both direction and energy level. It so happens that the administration of adrenalin affects the energy level of behavior but not its direction. Subjects given adrenalin, when asked to report whether they were experiencing an emotion, had some difficulty in deciding whether or not they were (7). They felt "stirred up" as they often did during emotion, but there was no environmental situation toward which this additional energy could be meaningfully directed. There was *no reason* for them to be afraid or to be angry. A few of the subjects reported that they felt "*as if* afraid." The outcome of the experiment was indeterminate, whereas actually the results would have been quite clear-cut in terms of different concepts. On the other hand, the effect of the removal of the cerebral cortex of cats was to disturb the *direction* of the behavior, so that the cat, when prodded by the experimenter, responded at an appropriately high energy level but directed his attack toward the table leg rather than toward his tormentor (2). Since the cat hissed and clawed, and since he could not be asked whether he was experiencing a true emotion, the investigator concluded in this instance that an emotion was being shown, though it was noted of course that the direction taken by the behavior was not appropriate.

Psychologists in general agree that the source of all energy in the organism is to be found in the processes of metabolism. A particular imbalance in the organism merely *releases* energy which is supplied by metabolic activity—that is to say, it draws upon supplies of energy available for *all* the activities of the organism—and it causes this "general" energy to be directed into a specific channel. If this be the case, the energy of emotions is the same as that of drives, and the energy employed in implicit responses is the same as that used in overt responses. In the light of these facts, psychology requires the development and the utilization of an over-all concept of energy mobilization—not merely the consideration of the phenomena of energy mobilization under various discrete headings.

There is already at hand a wealth of experimental data which may be utilized for the development of a more adequate concept of energy mobilization. The physiological studies of the excited emotions, for example, appear to be merely studies of one or another aspect of a general condition which might be labelled "energy level" or degree of mobilization of energy. In fact the very term "energy mobilization" was used by Walter B. Cannon in his studies of

[3] See the writer's discussion of this concept in reference 17, p. 187.

bodily changes in pain, hunger, fear, and rage (6). Nevertheless both Cannon and his psychological disciples have regarded emotions as a special category and have failed to turn their attention to energy mobilization in general. The same type of approach has characterized the studies of various physiological processes measured during sleep, during waking relaxation, during work and during excited emotions. These processes have usually been studied as relatively independent phenomena, and not as aspects of a more or less unitary condition which might be called the degree of mobilization of energy. Yet data from these studies, when brought together, permit the formulation of a more generalized concept.

In developing a concept of energy mobilization it is apparent that our problem is rooted in the energy storage and release of animals. Normal animals achieve from day to day a fairly constant energy balance, yet there are four important variables involved in this balance which increase or decrease at one time or another. These are (1) food, (2) stored energy, (3) work production, and (4) heat production (4). Mammals appear to be able to make choices among these four. For example, they may increase or decrease their food intake; they may dispose of more or less energy as work, as heat, or as stored protein, fat, or carbohydrate. In an experiment with German working men during the war, when limited quantities of food were available, the work output of the men was found in general to be proportional to the energy intake in the form of food. However, it was also influenced by a psychological factor referred to as "incentive pay." When cigarettes were promised to the men in return for extra work, there was a sharp rise in work output. This increase in work was accompanied by a loss in body weight, for the men under these conditions were drawing upon their stored energy reserves (4).

All four factors in the energy exchange may vary. The effect upon *behavior* of variations in food intake and energy storage is exercised, however, through their effect upon *energy release*, or work output in the broad sense of activities of all types. Of these four, then, it is the factor of energy mobilization which is of chief concern to the psychologist.

The term "energy mobilization" refers to the release of potential energy, stored in the tissues of the organism, for use in *activity* or *response*. This energy may be used for either covert or overt activity. It is the energy used in attending and thinking as well as in locomotion and manipulation. It is the energy used in tensing the muscles in preparation for overt response as well as that used in the overt response itself. Figuratively speaking, it is the rate at which the bodily engine is running.

The degree of energy mobilization, then, is the extent of release of the stored energy of the organism through metabolic activity in the tissues. This appears to occur in a continuum, from a low point during deep sleep to a high point during frantic effort or excitement. It is an aspect of response which is of basic significance. Among others, the following propositions can, I believe, be fully supported by empirical data:

1. Every activity, overt or covert, in which the individual engages requires the release of energy.

2. The extent of the energy release is determined by the degree of *effort* required by the situation *as interpreted by the individual*. For example, difficult tasks require more energy than easy tasks; situations which the individual regards as significant in relation to his goals release more energy than those interpreted as lacking this significance.

3. The extent of energy release is determined also by physiological factors, such as endocrine secretions, food, and drugs.

4. It can therefore be shown:

a. That the extent of energy release, or the degree of energy mobilization, varies on the average with the *type of situation* under which it is measured, and

b. That it varies with the *individual* when it is measured under the same stimulating conditions as objectively defined.

5. Variations in energy mobilization are an important factor in determining variations in other characteristics of an individual's behavior. For example, both reaction time and sensitivity to stimulation vary in the same individual with variations in the energy level. So also do the coordination of responses and the general quality of performance.

6. The relationship between energy intake and storage, and energy output as heat and work (or activities of all types, including the excited emotions) is an important factor in the general health and well-being of the individual, since too great a drain upon energy reserves will cause illness and breakdown.

I hope the mere statement of these hypotheses will indicate the scope of the topic with which we are concerned.

The question of measurement is basic in the development of any scientific concept. There are many unsettled questions with respect to the measurement of energy mobilization. However, the general direction which such measurement should take is clearly apparent, and only the details remain to be worked out.

Energy release is reflected in a number of physiological processes. These belong to one or the other of two interdependent systems: (1) the neuromuscular system, with central nervous control of the skeletal muscles, and (2) the digestive-circulatory system, with autonomic control of smooth muscles and glands. The energy mobilization itself appears to be directly controlled by the autonomic nervous system, but the central nervous system plays a major role in assessing the significance of situations, and thus in determining the amount of energy to be released. And the individual's response to the situations which require increased mobilization of energy demands postural changes and consequent tensions of the skeletal muscles, whether he engages in overt activity or merely assumes sets and attitudes which constitute a preparation for such activity. Muscular contraction, in turn, is accompanied by changes in the blood supply and the temperature of the active parts, so there are many different physiological processes which show consistent variations with variations in the stimulus situation and in the consequent degree of "effortfulness" or "arousal" of the individual. These measures vary in consistent fashion with variations in what may be conceived of as the continuum of energy mobilization of the organism. There are consistent changes from the sleeping to the waking state, from waking relaxation to work on easy tasks, from work on easy tasks to work on more difficult tasks, and from work on more difficult tasks to frantic effort or extreme excitement. Among the indicators of energy mobilization are three which I shall discuss briefly: skeletal muscle tension, palmar skin resistance, and the electroencephalogram.

(1) *Tension of the Skeletal Muscles.* Since any action upon the environment necessitates the contraction of skeletal muscles, these muscles might be expected to show increased contraction when the organism mobilizes energy for response—for the energy mobilized is energy which, in the last analysis, is to be used for muscular activity.

As an individual goes to sleep, action

potentials from the muscles *decrease* progressively until he reaches the stage of deepest sleep, when he moves least and is least disturbed by noises (30). As he awakens, there is an *increase* in action potentials (31). These electric potentials from the muscles indicate the degree of tension of the muscles, since contraction of a muscle produces electrical activity in that muscle. When a sensory stimulus is applied to the sleeping person, or when a dream occurs, there is usually an increase in action potentials (30). Under these conditions the individual is mobilizing more energy than during undisturbed sleep.

At the opposite end of the continuum of energy mobilization from that of sleep, is that of the startle response or that of intense excitement. Under such conditions widespread and intense contraction of skeletal musculature has been reported (26).

Degrees of energy mobilization intermediate between those of sleep and those of extreme excitement are found during most of the "everyday" activities in which we engage. Studies of such activities show that, as they increase in difficulty, there is an increase in tension of the skeletal muscles. When these activities are interfered with by distractions or obstructions, there is also an increase in tension. When, on the other hand, an individual becomes habituated to a performance or a situation, and it thus becomes less difficult or threatening to him, his muscular tension decreases. Only a few of the many studies in this area can be described.

A number of investigators have shown that increased tension of the skeletal muscles regularly accompanies "attention," "set," "imagining," and "thinking," as compared with resting states (21, 31). Others have reported that subjects showed an increase in action potentials from the arm muscles with each succeeding step of difficulty in arithmetic problems upon which they were working. It was found that the increase occurred whether the subjects reported success or reported failure in solving the problems; thus it could not be said to be due to the frustration of failure (12). Men undergoing flight training were found to show more tension of the muscles during the solo stage of training than during other stages, and during the maneuvers of take-off and landing than during other maneuvers (37). Finally, action currents recorded from electrodes placed just above each eyebrow revealed that simple tracking produced a significantly higher level of tension than reading, solving simple mathematical problems, or simulated lookout—these latter tasks differing little from each other in the tension level accompanying their performance (35). Clearly, there is a positive relationship between the energy demands of the task and the muscular tension of the individual.

Variations in tension during the same task have been used as measures of alertness. Muscle action potentials decreased progressively as the subject became progressively less alert, if decreasing alertness is indicated by progressively longer simple reaction time and progressively less efficiency in performing the task (22). With appropriate stimulation there was recovery of alertness, indicated by a higher general tension level, shorter reaction time, and more accurate performance. In the light of these findings, an alertness indicator has been designed which turns on a panel light when the subject's electrical output reaches a specific minimal level.

It seems clear that, when other factors are constant, the degree of muscular tension of the individual varies directly with the demands of the task and the corresponding degree of alertness or effort shown by the individual. The continuum of muscular tension ap-

pears therefore to correspond with the continuum of energy mobilization.

(2) *Palmar Skin Resistance.* The resistance of the skin to the passage of a minute electric current, especially through its palmar or plantar surfaces, varies consistently with variations in the type of stimulus situation in which it is measured. Whatever may be the precise nature of the phenomenon, there appear to be consistent variations in skin resistance with variations in the energy demands of the stimulus situation. This fact suggests that the measure may be employed as an indicator of energy mobilization.

In sleep, palmar skin resistance is very high. Going to sleep does not represent a sharp break from a previous condition; instead, as the individual gradually becomes more drowsy and relaxed, the skin resistance gradually rises (23). In one study where the subject was in a Morris chair turned away from the observer, the experimenter, by watching the changes in electrical resistance, could always tell when drowsiness was coming over the subject (23). One investigator reports that persons in whom sleep is accompanied by a great increase in skin resistance are persons who sleep soundly and are hard to awaken, while persons who show only a slight increase in resistance sleep lightly and are easily aroused (23).

It is generally agreed that resistance is lower during work periods than during rest periods; that the presentation of a stimulus causes a *drop* in resistance; that very soon after the cessation of stimulation, resistance begins to rise toward its former level. More difficult tasks, situations of greater significance, or situations the individual is unprepared to meet, cause greater decreases in resistance than easy tasks, situations that are less significant, or situations the subject feels able to cope with.

A striking illustration of the relationship between skin resistance and the demands of the situation is to be found in a study of skin resistance during the activity of fencing. For example, it has been reported that novices learning to fence showed great drops in skin resistance at first but, as they mastered the task, the drops in resistance became much smaller (33). On learning new techniques, the size of resistance drop varied inversely with the similarity of the new task to the previously learned tasks. When engaged in free combat, both novices and masters showed constant galvanic responses, or sudden drops in skin resistance. The size and frequency of these responses depended upon the difficulty of the contest.[4]

In other studies the galvanic responses to words have been shown to vary with the meaningfulness and importance of the words (3). It has also been reported that galvanic responses involving replies to questions about provocative social problems were smaller if the replies were in harmony with group opinion than if they were not, and that in general "yes" responses were associated with smaller galvanic reactions than "no" responses (32).

So regular is the occurrence of a galvanic response when a so-called emotion-arousing stimulus is presented that at one time it was actually believed that the galvanic response might be specific to emotional conditions. Since the excited "emotions" always have as one of their characteristics a high energy level, any physiological indicator of energy

[4] Less questionable evidence of the relationship between skin resistance and the demands of the situation could easily have been presented. The illustration employed was chosen for the color it added to an after-dinner speech, and it is included here in the interest of fidelity to the remarks made at that time. The study would not have been included, however, had its findings not been in harmony with those of other investigations known by the writer to be entirely reliable.

level would be expected to show a close association with the condition ordinarily labelled "emotional." We may note, for example, the fact that skin resistance phenomena have been found useful in detecting the excitement that accompanies the telling of a lie and that produced by various motion pictures.

Further evidence of the nature of skin resistance phenomena is found in the studies of the *adaptation* of skin resistance in various situations. The galvanic response decreases progressively with repetition of a given stimulus situation. In fact, even the general level of skin resistance decreases on successive days when the subject is repeatedly placed in the same stimulus situation—provided only that the situation is not so complex that on successive occasions he continues to perceive new aspects of it (11, 16).

Apparently, *activity*, or readiness for activity, is the common factor in all situations where *low* skin resistance is found in a given individual. Relaxation or passivity, on the other hand, appears to be the common factor in all situations where *high* skin resistance is found. If a decrease in resistance occurs (with certain limitations) whenever there is an increase in energy mobilization, it is not surprising that decreased resistance has been variously considered to be characteristic of emotion, of volition or conation, of a sudden check in the comprehension of problems, and of states of alertness. All these conditions involve increased effort or mobilization of energy. In harmony with this interpretation also is the *decrease* in resistance which occurs with the presentation of a stimulus or the beginning of work, the progressive *increase* in resistance which occurs during rest periods, and the *adaptation* (or progressive increase) in resistance which occurs upon repeated presentation of a simple stimulus situation. The continuum of palmar skin resistance, like that of muscular tension, appears to correspond at least roughly to the continuum of energy mobilization.

(3) *The Electroencephalogram (EEG).* The electroencephalogram, or EEG, is a record of electrical potentials from the brain. It is a third measure which appears to vary consistently with variations in the individual's activity level or energy mobilization. We must be cautious, however, in regard to conclusions about this measure, since experimental work in the field is of comparatively recent origin.

Brain potentials vary in two dimensions—frequency and amplitude—that is to say, they may be fast or slow, and they may be large or small. It has been found that, when the individual is at rest and is not subjected to external stimulation, the human brain has an electrical beat or rhythm of it own. This beat is diminished or abolished by certain types of sensory stimulation, or even by the expectation of such stimulation (29). The larger, slower waves around 10 per second, known as alpha waves, are characteristic of waking relaxation. Upon stimulation, they tend to disappear and to be replaced by low potential, fast activity—*i.e.*, by what are called beta waves. Attention focused on a problem, even when there is no sensory stimulation, may block the alpha rhythm (28). There appears to be a parallel between the intensity of the mental effort demanded in a situation (rest period, anticipation of a problem, work on a problem, and recovery period) and the changes in the rate of electrical activity of the brain (36).

Stimulation of the kind called "emotional" changes the character of the EEG in striking fashion. Darrow and his associates found that alpha waves decrease and beta waves increase after such stimulation (9). Others have reported that alpha waves were abol-

ished, or practically abolished, by fright, embarrassment, or apprehension (28).

Conversely, as an individual goes to sleep, alpha waves are replaced, not by smaller and faster waves, but, when deep sleep is reached, by slower and larger waves, called delta waves (28). Falling asleep represents no sharp break from a preceding waking state. If an individual merely lies quiet for two hours or more, there is a striking reduction in the frequency of the alpha waves (29). As he becomes more and more drowsy, the rhythm becomes less and less frequent and the amplitude smaller. Sounds or other disturbances during sleep, even though they do not awaken the sleeper, will cause the alpha rhythm to reappear (29). Dreams occur chiefly during the brain wave records characteristic of the lighter stages of sleep (28).

Fatigue has been found to reduce the alpha rhythm and to produce some of the random, slow waves which often occur in sleep. These disappear and the EEG tends to return to normal when caffeine is taken (28).

The marked decrease in brain potentials during severe fatigue or sleep has made it possible to construct a device which, by recording brain potentials, can signal when a man becomes inefficient, either because of severe fatigue or because of oxygen deprivation. The device is set to signal all frequencies of brain potentials lower than 8 per second and never to respond to frequencies above 8 per second. This signalling device could be used to inform an airplane pilot when any member of his crew was falling asleep or becoming affected by oxygen deprivation, or it could be used to set off an alarm system when the driver of an automobile was falling asleep (1).

The EEG shows *adaptation* effects with repetition of the same stimulus situation. For example, auditory stimuli which block the alpha rhythm lose their effectiveness after a few repetitions, and persistent, unchanging stimulation with light flashes soon leads to a return of the alpha rhythm.

Brain waves are typically large and slow during deep sleep, faster and smaller during waking relaxation, and very fast and small during mental effort. In extreme excitement there is likely to be a loss of all rhythm in electric potentials. A loss of rhythm of the potentials also occurs in very deep sleep. Perhaps in deep sleep there is too little activity of the brain to produce well-marked rhythms, while in extreme excitement there is activity of so many different parts of the brain that there is little synchronization. Where rhythms appear at all, their frequency is in general lower in states of low energy mobilization than in states of high energy mobilization. In other words, large, slow waves are usually found during conditions of relaxation, while small, fast waves are likely to be found during effort, tension, or excitement. However, the picture is not entirely clear-cut. Some investigators suggest that the relationship between the EEG and other bodily changes is different during cortical domination from that found during subcortical domination (10).[5]

With the exception just stated, it is clear that muscular tension, palmar skin resistance, the electroencephalogram, and a number of other physiological

[5] The electroencephalogram, though it shows consistent variations with variations in energy mobilization, is not as direct an indicator of the degree of mobilization of energy as the other two measures discussed. The EEG apparently reflects both cortical and subcortical activity, and thus it is not an uncomplicated indicator of the energy level of response. It is of interest to note, however, the extent to which it shows variations with variations in the energy demands of the situation and the general organic condition of the individual.

measures, show more or less consistent changes in one direction upon relaxation and in the opposite direction upon stimulation. The extent of the change seems roughly proportional to the extent of the relaxation or the stimulation. These measures may therefore be regarded as at least rough indicators of a condition which might be described as the degree of energy mobilization.

(4) *The Intercorrelation of Measures.* When simultaneous measurements are made of the various physiological processes assumed to be indicators of energy mobilization, these measures show consistent correlation with each other, but the degree of correlation is not always high.[6] There are a number of factors which may account for the lack of a closer correspondence between measures. Among them are errors of measurement, the fact that certain processes probably come close to their physiological limit before that limit is approached by other processes with which they are being correlated, and the fact that particular processes may, in order to maintain homeostasis, begin at a certain point to function in compensatory fashion. Such compensatory functioning has been noted, for example, in the case of blood pressure and heart rate (8, 5). The correlation of measures is also lowered by the fact that there appear to be individual differences in the responsiveness to stimulation of the various physiological systems, so that in one individual exciting stimuli will have their greatest effect upon one system and in another individual upon another system (5, 24, 25). And, finally, it is possible that there are differences between measures in the degree of "generality" of the energy mobilization which they reflect (18).[7]

In spite of such interfering factors, it has been shown that, when subjects pushed against spring balance scales, there was a regular *decrease* in skin resistance with each increment in muscular tension (19); that rate of respiration during mirror drawing showed a correlation coefficient of .84 with muscular tension in the active hand (34); that palmar galvanic response showed a correlation of .51 with the increase of beta rhythms in the EEG and a correlation of .50 with the decrease of alpha rhythms (9); that cortical potentials during mental work showed a correlation of .59 with heart rate (20); that there was a high positive correlation between the increase in the frequency of the alpha rhythm and the increase in basal metabolic rate produced by administratering thyroid to normal subjects (5); and that, when the EEG was studied in conjunction with a number of measures of the functioning of the autonomic nervous system, the stimuli which produced the greatest effect on the vegetative functions also produced

[6] Because there are many factors which would distort a rectilinear relationship between the various physiological measures, it seems probable that correlation techniques such as the Pearson product moment formula do not represent adequately the relationship between measures.

[7] There are a number of different ways in which the organism may consume the energy released. Variations in the *direction* of the energy release occur *within the organism* as well as with respect to the external environment. Energy is not released to the same extent in every group of tissues at any given moment. A perfect correlation between measures of the activity in various tissues is therefore not to be expected. The extent of the intercorrelation of any two measures may be taken as an indication of the degree to which those particular "conversion mechanisms" are tied together in their activity. However, as R. C. Davis has suggested to me privately, whatever the variety in the modes of energy conversion of the organism, these various modes of consuming energy can be ordered according to the amount of energy converted —expressed, for example, in some such terms as calories per minute. This common factor found in the various particular modes of consuming energy provides the justification for the more generalized concept of "energy mobilization."

the most marked inhibition of the alpha rhythm (28).

Such findings serve to reinforce the opinion that "energy mobilization," or the intensity of response, is a meaningful concept well substantiated by present data. It appears, therefore, that there is justification for the use of such a concept in psychology.

Summary. The thesis of my paper is that there is a basic aspect of behavior which may be referred to as energy mobilization or energy level. This aspect of behavior is present in *every* response, and it determines in certain important respects the characteristics of the behavior as a whole. Current psychological concepts incorporate the notion of energy mobilization, but always as *part* of some other concept, such as emotion or motivation, the other part of the concept being that of the *direction* of the response. Dual concepts, or concepts which incorporate two aspects of behavior which may vary independently, have retarded the progress of psychological investigation. It is suggested that certain of the descriptive categories of psychology be replaced by the two basic concepts, energy mobilization and direction, which, combined in various ways, now constitute the full content of these concepts.

An attempt has been made to clarify further the meaning of the concept of energy mobilization. It has been shown that there are a number of physiological measures which vary in consistent fashion with variations in what appear to be the energy demands of the situation, from the lowest demands in deep sleep to the highest demands in frantic effort or extreme excitement. Intermediate between these conditions are the relatively low energy demands of waking relaxation, the greater energy demands of work on simple problems, and the still greater energy demands of work on more difficult problems. With each increase in what appears to be the energy demands of the situation there is a corresponding and consistent change in every one of a large number of physiological measures which, because of this fact, may be regarded as at least rough indicators of energy mobilization.

It is proposed that further study be devoted to the concept of energy mobilization as a primary dimension of behavior. Present data suggest that variations in energy mobilization are accompanied by variations in the speed and intensity of response, and in the sensitivity of the organism to stimulation. They also indicate that there are persisting individual differences in this aspect of response, with widespread effects upon both the health and the social adjustment of the individual. If these propositions are valid, the concept of energy mobilization is a basic concept in psychology.

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TIME AND AGGRESSION[1]

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Motivational constructs such as need, force, and libido have over the years succeeded in displacing most of the structuralistic orientations which reigned supreme during the time of Titchener. It seems that the present-day search for measurable intervening variables has largely ignored the conceptual tools of the "past." We are here not referring to the methodology of introspection but rather to the topics of scientific inquiry which were so vigorously pursued by Wundt and many others both before and after the formal establishment of an experimental psychology.

One such topic concerned itself with the psychological experience of time. Boring (1, 2, 3) in giving an historical summary of this subject matter has also contributed a considerable amount of stimulating insight into the entire problem of duration. He has in this connection suggested (2) that the problem of protensity might be solved if perceived duration could be reduced to an intensity which substitutes for protensity. According to Boring, duration implies a process in time and this term "process" means that something that is not time itself changes or varies in time. This conception of duration will be tentatively modified by the proposition that the psychological experience of duration be considered as a process in its own right.

It is necessary, first of all, to appreciate the need for a transition from the introspective judgment of time to a study of duration with respect to observable and recordable changes in behavior. Following the lead of Watson, psychology turned to behavior because scientific progress demanded an increased observational univocality. The individual's experience and accompanying verbal account of phenomena may have been more profound, but they had to give way to a pressing need, probably induced by the physical sciences, for what is basically a social or majority verification of the psychological datum. The experience of duration can be observed by an individual and described to others who then form a notion of the verbalized account by empathizing with it in terms of their own experiences. Unfortunately a judgment of duration which one records verbally must of necessity become a "mere" inferred or intervening variable in a study, for example, of rat behavior.

Studies of temporal orientation in the rat have been shown to be possible by Hunter and Nagge (12) by means of the double alternation problem in a temporal maze. Recent studies on estimated duration reflect the more modern stress on motivation. Rosenzweig and Koht (17) demonstrated that subjects who need time in order to finish a certain task will consistently underestimate objective duration. Filer and Meals (6) have discovered the complementary fact that overestimation of duration occurs when subjects know that they will be rewarded at the end of a given period.

We should like to propose that duration *per se* is capable of assuming the role of an "intervening variable." It is customary to introduce intervening variables whenever an unknown but assumed process is found to be necessary for the functioning of an organic or inorganic

[1] The experiment described in this paper was supported by a research grant from the National Institute of Mental Health, U. S. Public Health Service.

system. As is known, stimulus-response and sign-significate theories of learning present the observable foci-pair in such a manner as to allow for the introduction of postulated variables which are believed to intervene between and to make possible the acts of stimulus input and behavioral response. As long as a postulated process or structure remains empirically undemonstrated, it is usually referred to as an intervening variable.

Let us extend the term "duration" and henceforth refer to it as meaning "psychological duration."

A distinction must be made between three different kinds of time experience:

1. Duration may be the experience of objective time. The organism is behaving in harmony with an arbitrarily absolute time mechanism. One hour on the clock is here simply experienced as not more or not less than one hour. This is an ideal situation and probably never happens under natural circumstances, although a realized or unrealized striving to keep in line with objective time may have significant psychological implications for the understanding of the person.

2. Duration can be experienced as a sequence of events, that is, it appears in terms of objective happenings. This is experience of duration by means of things functioning in a given way, with a certain beginning and a certain end.

3. Experience of duration as if existing independently of things, persons or other absolute criteria. Whenever the passage of time itself becomes an object of attention we may speak of an experience which is motivated by a psychologically determined need to manipulate time. The acceleration of time flow may be wished for because it allows the speedy consummation of a goal object.

In general, psychological duration is a state of anticipatory cognition consciously experienced or functioning as a physiologically determined catalytic agent of behavior. The definition of psychological duration can be given as: *events in time, manipulation of time, and the relationship to objective time (clock).*

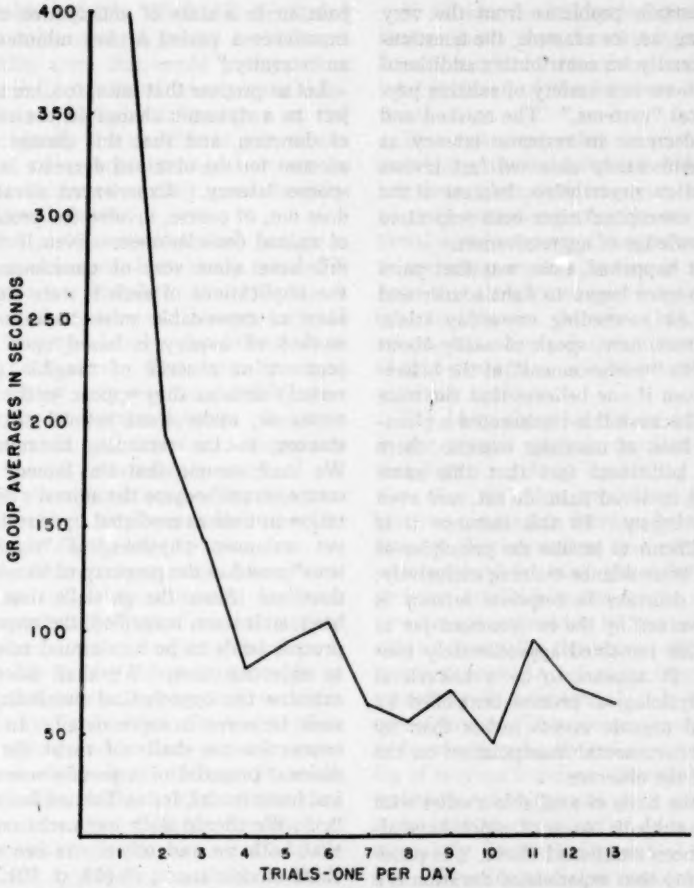
Intervening variables can be beneficial devices for the development of research hypotheses if they can be operationally defined. Pratt (16) in discussing the role of operationism in psychology makes several statements which must be taken into account for an appraisal of unverified constructs. These are: (1) that explanation is the statement of a correlation, (2) that the meaning of concepts should be identical with the facts obtained, (3) that theoretical explanation is essentially circular or tautological. This approach to theoretical formulation invites a certain degree of modesty in regard to the amount and imaginative quality of inferential constructs.

The operational definition of psychological duration is as follows: (*a*) *The time which elapses between a stimulus (internal or external) and a response (behavioral or internal),* (*b*) *The time which elapses between a response and a subsequent stimulus-receptive threshold.*

EXPERIMENTAL RESULTS

The concept of psychological duration arose in connection with an experiment dealing with response latency as a measure of habit strength in relation to spontaneous fighting in homozygous male mice (7). The term "spontaneous" refers to vigorous fighting in the absence of any sort of discernible physiological traumata, and is contrasted with competitive fighting (8) which involves a struggle over needed objects such as food.

A measure of response latency was obtained by timing the onset of fighting in pairs of mice. The figure shows a



Response latency curve of spontaneous fighting for 10 pairs of C57 male mice.

graph of the data. These results are based upon the group means of ten pairs of mice. The decrease in response latency is marked during the first three trials; thereafter the latency becomes asymptotic. For present purposes the essential point is that response latency in spontaneous fighting behavior decreases with practice.

These findings are particularly suggestive because we are here dealing with a social relationship of considerable complexity. One is tempted to entertain the notion that there exists a certain amount of lawfulness in the development of social interactions.

PSYCHOLOGICAL DURATION

The specific hypothesis is that the decrease in fighting response latency can be fitted into a theoretical frame of reference by assuming an increase in psychological duration. Such an attempt

raises certain problems from the very beginning, as, for example, the questionable necessity for contributing additional speculations to a variety of existing psychological "systems." The marked and stable decrease in response latency as an experimentally obtained fact invites explanation, nevertheless, because of the lack of conceptual rigor with respect to our knowledge of aggressiveness.

What happened, then, was that pairs of male mice began to fight sooner and sooner on succeeding one-a-day trials. We cannot, here, speak so easily about a possible "reinforcement" of the behavior. Even if one believes that the mice fought because this represented a pleasurable form of muscular exercise, there is the additional fact that this same fighting involved pain, defeat, and even serious injury. In this instance it is very difficult to invoke the principles of reward or avoidance-training exclusively.

The decrease in response latency is not governed by the environment *per se* since this remained approximately constant. It appears to be a behavioral and physiological process controlled by internal organic events rather than by any environmental manipulation on the part of the observer.

On the basis of available studies with human subjects, some of which have already been mentioned above, it is possible to say that experienced duration is a function of the kind of emotion or feeling tone which organism-environment interactions generate. Psychological duration is often increased relative to an objective time continuum by exposure to painful stimuli and decreased by experiences which are satisfying. More explicitly, something unpleasant is more likely to *seem* as if it were lasting for a long time than something pleasant, which appears to last for exceedingly brief time intervals. A person absorbed in work is hardly aware of the flow of time, someone who is bored, in great pain, or in a state of anticipation may experience a period of five minutes as an "eternity."

Let us propose that mice, too, are subject to a dynamic change in the sense of duration, and that this change can account for the obtained decrease in response latency. Experienced duration does not, of course, involve the problem of animal consciousness. Even if mice did have some sort of consciousness, the implications of such a state would have an expendable value because the method of inquiry is based upon the presence or absence of tangible (not verbal) data as they appear to the observer or, under more refined circumstances, to the recording instrument. We shall assume that the latency decrease occurs because the animal's orientation in time as mediated by certain as yet unknown physiological "mechanisms" now has the property of increased duration. Since the animal's time has been, as it were, magnified, the response process tends to be accelerated relative to objective time. We shall later on examine the hypothetical possibility of such an event in more detail. In this connection we shall not resist the additional proposal of a pseudo-neurological brain model, for as Tolman has said, ". . . We should stick our necks out so that both we and others can see what these models are . . ." (19, p. 50).

The following statements constitute the background for a systematic presentation of some assumed events in the central nervous system:

1. When a response latency decreases more or less gradually it is permissible to infer that psychological duration has increased relative to an objective criterion of time.

Psychological duration is considered here as an intervening variable responsible for the change in latency. Its use as a construct is similar in intent but not in meaning to the Hullian concept

of habit strength. Hull (10) has stated that habit strength cannot be observed directly since this would presuppose a more fully developed knowledge of complex neurological relationships; on the other hand, it is possible to give an account of antecedents which result in habit formation as well as of the subsequent behavior.

The postulates which Hull has given are based upon individual, non-social behaviors. Postulate 15 (11) has a direct relevance to the decrease in fighting response latency determined in a social situation. This postulate concerns itself with reaction potential as a function of reaction latency. Reaction potential is postulated as a negatively accelerated decreasing function of the median reaction latency. The figure indicates that similar results were obtained in the present study.

The decrease in response latency cannot be completely accounted for by a restricted mathematical treatment of the obtained data. Response latency is probably a dependent variable in a situation where independent variables are located primarily in the central nervous system and hence not freely accessible to behavioral studies. It seems permissible, under the circumstances, to postulate a few of those hypothetical events which give an account of how the obtained data were possible in the first place. Of course, such attempts should be consistent with the actual observations. In the present instance one of the assumptions that we permit ourselves to make is that a magnified experience of duration would tend to lead to a decrease in latency. It is obvious that one cannot stop at the concept of psychological duration, since it is only a link in a chain of central events. We shall try to suggest later on how, specifically, psychological duration is increased, as well as the relationship of such a process to a decrease in response latency.

2. An increase in psychological duration as shown by a decrease in response latency might be considered as behavioral evidence of the existence of emotional stress.

This statement refers in part to the possibility that accelerated behavioral reactions when deviating from a given norm be considered as evidence of emotional malajustment. Observation tends to encourage such a notion in clinical cases that show hyper-sensitive, so-called neurotic behavior. Meerloo (14), among others, has observed such disturbances of time conception in both neurotic and psychotic patients.

The basic objective datum employed in the present analysis consists of the fact that a regularly intervalled repetition of a situation producing fighting behavior results in a decrease in response latency. Let us assume that succeeding superimposed trials of the fighting experience establish traces in the central nervous system, which in turn are capable of decreasing the latency of the response process. A valuable concept discussed by Woodworth (21) is that of consolidation. This process would seem to involve a spatially enlarged patterning of nervous impulses. Emotional disturbances which appear as a result of stress may be conceived of as involving a spatially determined spread of excitation. Thus the partial or complete abolishment of emotionally grounded distress symptoms, for example, anxiety, has been achieved by the surgical procedures of lobectomy and lobotomy. Both types of surgery involve the disruption of spatially patterned neural configurations. In the case of lobectomy a spatially defined area is simply removed, thus limiting a harmful development of neural permutations. On the behavioral level this does away with feelings and behaviors which are by implication isomorphic with the function of cerebral structures. A lobotomy is less radical because

the disruption of neural patterns is attempted. In the former procedure the cerebral geometry is changed by the actual removal of field vectors, the latter method on the other hand is an attempted fragmentation and isolation of neural nets for the purpose of an *ad hoc* but beneficial reorganization of structural relationships. Whenever one speaks of a possible isomorphic condition between nervous system function and behavior, one is at the same time involved in an account of how the spatial patterns of a three-dimensional area, the brain, function through and upon behavior. The process of an emotional-verbal catharsis in directive and non-directive psychotherapies again seems to involve the re-integration of behavior patterns by means of a spatially oriented process of "emptying" and "re-packing."

In accordance with Boring's (2) approach we have attempted to reduce protensive variables to spatial patterns. The long intervalled process of consolidation (at least twenty-four hours between trials) should have led to a considerable strengthening of the fighting response trace system. We are, of course, assuming that the effects of retroactive inhibition are here kept constant. In other words, the behavioral expression of a possibly innate response has become habitual.

Development of these inferences depends upon the notion of a trace increasing in strength. A considerable amount of help is derived in this connection from existing results in psychophysics in relationship to the time error. Pratt (15) in a tone stimulus comparison experiment has found evidence to the effect that both fading trace and assimilation phenomena are of importance for a lowering of the PSE. Despite these complications we allow ourselves to suppose that an increase in trace strength by repetition is capable of having an accelerating effect upon response latency.

An additional fact available to us, untainted by analogy, is, of course, the fighting behavior itself. It should be stated that the writer entertains no absolute convictions in regard to the relative importance of innate (instinctive) or learning variables as far as aggressiveness is concerned. In a previous publication (8) it was tentatively concluded that aggressive behavior in mice cannot be accounted for by frustration as a single or exclusive cause. On the other hand, it was possible to demonstrate experimentally that the behavioral expression of aggressive urges is highly susceptible to training. For practical purposes and until more information is available, one may subscribe with some confidence to the hypothesis that aggressiveness is an inborn "trait." This statement can be supported by the fact that male baby mice will fight spontaneously at 34 days of age, in the absence of frustration (8).

A tentative solution of the instinct vs. learning problem has been provided by Lashley (13) who proposes that differences between learned and instinctive behavior are differences in degree of plasticity and adaptability only, not in kind.

Fighting behavior is conceived of as a discharge of energy. Such a discharge presupposes the activation of a discharge mechanism. We hold that it is this discharge mechanism which brings about the decrease in response latency. The following conditions might be relevant for this function:

a. Repetition of the fighting behavior, which would lead to a strengthening of a given trace system by a summation process. This should be possible neurologically if the repetitions occur at not too frequent intervals, thus avoiding fatigue effects. In essence, the process of repetition should result in a gradual

accumulation of coinciding discharge traces.

b. Response latency as a behavioral form of resistance to the discharge of motor movement. A decreasing latency would, therefore, imply the lowering of a threshold for the behavior under consideration. A lowered threshold would in turn lead to a decrease in latency.

c. From a neurological point of view, the lowering of threshold plus the cumulative effects of repetition should give rise to a so-called reverberating circuit. Such a circuit would have reflex properties, but on a central rather than peripheral level. It would, in the absence of inhibiting factors, be capable of reproducing its own pattern indefinitely, given, of course, the requisite amount of energy. An obsessive-compulsive neurosis may by analogy be the result of abnormally functioning "reverberating circuits." Such circuits should not suggest themselves necessarily as final and absolute causes, especially in regard to psychopathological states.

d. The decreasing response latency is a function of the strengthening of the circuit path by means of repetition and a lowering of the path resistance by means of the accumulation of memory traces.

This hypothetical account must for the present avoid the problem of discribing the mechanism which governs the latency decrease directly. Let us for the moment consider this problem as a "technical detail."

The preceding account makes it somewhat apparent that we lean heavily upon the law of exercise. One should like to suggest here the significance for future developments of psychological theory of Boring's (2) suggestion that perceived duration be reduced to an intensity which substitutes for protensity. Any account of central processes should, needless to say, be based upon a quantitative point of view. Let us assume that intensity is a function of frequency. Let us propose, furthermore, a concept of velocity, defined as a latency decreasing function of repetition. One could now be in a position to describe psychological duration as an intensity function, and in this way account for the basic hypothesis, namely, that an increase in psychological duration decreases response latency.

Upon approaching psychological duration from the point of view of intensity we find it possible to suppose that duration is experienced as increased because of an increase in velocity (a function of repetition leading to increased intensity).

In conclusion, it seems possible that duration is experienced as longer because of an increase in neuro-physiological activity per unit of objective time. Such an increase in physiological gradients should occur most often under conditions of stress. This view would harmonize with the "raw" observation that time seems to last longer under conditions of psychological and somatic stress. An approach of this type has recently received some encouragement from experimental results in puppies (9) in which the writer found that behavioral distress symptoms were correlated with the manner in which a given length of time was spent in a small isolation box. Massed experience in this box resulted in relatively more excitation than distributed experience. It was concluded that periodic exposure to a frustrating situation is less disturbing to the organism than continuous exposure when time is held constant. In general, the results indicated the importance of stimulus duration as an ingredient in traumatic experience. The protensive patterning of stimulus duration as an event imposed upon the organism gives rise to distress by a lengthening of the psychological experience of such duration.

Boring (4) has suggested another

type of raw observation: "Under conditions of stress, time seems to progress more quickly or at least not to move slowly (that takes account of not being aware of time at all when stress is great); but after conditions of stress, time seems to have progressed more slowly."

By using animal subjects one is prevented from checking upon the kind of conscious experience of time which they are aware of. We believe that the qualitative problem of time experience must be developed in terms of at least two different types of situations: (a) the traumatic event, involving discomfort and fear because of the sudden impact of uncontrollable stimuli; these are stress conditions under which time may move rapidly; (b) anticipatory states, involving anxiety or a delay of goal object consummation; here time may progress more slowly as compared with objective time.

A consideration of time on a psychological level can be applied to the "cognitive map" concept proposed by Tolman (18). He has made a distinction between narrow strip-like and broad comprehensive maps which organisms build up by means of commerce with the environment. The path connections of a narrow map are relatively fixed, whereas those of a broad map are complex, permitting a successful solution of new orientation problems.

Narrow strip maps, according to Tolman, are induced by (1) brain damage, (2) indistinguishable environmental cues, (3) excessive repetition of a single path goal problem, and (4) by too intense motivation or frustration.

The fourth point was developed further by Tolman in terms of the suggestion that many intra- and inter-individual maladjustments be interpreted by means of a narrowing of the cognitive map because of overly intense motivation or frustration. Psychoanalytic concepts such as fixation and regression are then considered by him in the light of cognitive maps.

It seems to us that Tolman's third point, repetition, needs further detailed explanation. Why does an overdose of repetition lead to the formation of a narrow cognitive map? By adding the factor of protensity as another dimension of behavior response, it may be possible to think of a cognitive map as remaining narrow when the trace system of a given reverberating circuit is strengthened by repeated exposure to a given situation. This hyper-functioning of a limited brain sector might in turn precipitate ever-decreasing response latencies to environmental cues. The accompanying magnification of the psychological time span could result in an incapacity to react more slowly, that is, to delay, and thus to permutate on a cognitive level various other possible path sequences before the actual discharge of motoric functions. In other words, a narrow cognitive map may involve not only a limited spatial orientation but also a distortion of time perspective.

PERCEPTUAL HOMEOSTASIS

So far, little attention has been paid to the behavior upon which present experimental results and theoretical speculations are based. Fighting, as has been pointed out before, is a socially determined relationship quite different from situations where a single rat finds itself in a maze and where the components of the maze remain constant and reliable, at least during a given trial. We have tentatively designated such fighting between two mice as spontaneous because they were not physiologically frustrated.

Observation of mice commencing a fight shows a preceding period of extreme restlessness. This behavior is so striking that one is led to suppose that

the effect of two mice freely moving about reacts upon both in an "unfavorable" manner, as shown by the ensuing restlessness immediately upon meeting.

The term "perceptual homeostasis" describes a need for perceptual balance. This represents an extension of Cannon's (5) concept of homeostasis, which is restricted to inner physiological balancing processes. Perceptual homeostasis will be defined as a psychological need to predict and to control environmental stimuli.

The behavior of two mice who are watching each other is difficult to predict. From the point of view of one organism, the other one is seen as a stimulus, moving about, coming closer, or retreating in an ambiguous manner. A single mouse, on the other hand, in a single maze with a single constant goal point can be quite certain that correct performance will produce the expected reward. Behavior in such a situation would be a function of the state of physiological homeostasis.

Fighting between laboratory rodents usually stops when one of the pair has beaten, or rather bitten, the other one into submission. Under such circumstances the victor will cease his attack when the loser retreats into a corner and remains there in a motionless defense posture.

The relationship between perceptual homeostasis and psychological duration is based upon the notion that a demand for stimulus mastery includes the additional dimension for time. In the case of an unpredictably moving stimulus the probability of its entering a state of rest at a certain place and at a certain time is uncertain. The fighting response attempts to bring into balance an irregularly patterned process of perception.

The concept of perceptual homeostasis may find application in behavior situations not marked by aggression alone. Tolman and Brunswik (20) have proposed that orientation in the environment is governed more by probabilities than by certainty. Emotional stress could be a function, in part, of the degree of perceptual homeostasis. In addition to speaking in terms of probability relationships, one could describe the effects of stable and unstable environments upon individuals and groups. One can in any event hope to discover more than a casual relationship between unpredictable environmental stimulus configurations, both in terms of space and time, and aggression as an attempt at attaining stability of perceptual experience. Development of this concept must be postponed until more research data become available. A behavioral quantification of this process is now in progress.

Anyone making use of intervening variables within an explanatory frame of reference will sooner or later face the fact that it is not enough to let these variables remain in a state of nebulous inference. No amount of refined or less refined mathematical treatment can substitute for a direct experimental attack upon unseen, but suspected phenomena. For psychology this would mean increased cooperation with various biological disciplines. It is not enough to propose brain models; such verbal behavior or analogizing should be accompanied by hypothesis-testing through coordinated neuro-psychological research teams.

The following formulations may be considered as conceptualized research problems to be solved in the future:

Given: R (repetition), B (behavior), L (response latency), T (trace strength), S (response threshold), Ctr (reverberating circuit), D (psychological duration), + (symbol for increase), − (symbol for decrease), ⊗ (symbol for interaction), ↔ (symbol for relationship), ∟ (symbol for correlation).

It was proposed earlier that psychological duration (D) stands in significant relationship to:

a. Trace strengthening
b. Lowering of response threshold
c. Reverberation of an established trace circuit
d. Decrease in response latency

Only the last variable can be considered as a quantified derivative of the entire process. It was gotten by a measurement of the period elapsing between first perceptual contact and the onset of vigorous fighting. All the other variables, except the fighting, are of the intervening, or more correctly, assumed kind. A justification for proposing them in the first place rests upon the hope that evidence may be found for them by means of psychological and biological research.

SYMBOLIC CONSTRUCTS

1. The strengthening of a trace (T):
$T^{+} \leftrightarrow R \otimes B$: an increase in trace strength is related to an interaction process of repetition and the specific behavior.

2. The lowering of a response threshold (S):
$L^{-} \leftrightarrow S^{-}$: a decrease in response in latency stands in direct relationship to a decrease in response threshold.

3. Reverberation of an established trace circuit (Ctr):
$Ctr^{+} \leftrightarrow S^{-} \otimes R^{+}$: the strength of a reverberating circuit stands in direct relationship to the interaction of a lowered response threshold and increased repetition.

4. The decrease in response latency (L):
$L^{-} \otimes Ctr^{+} \leftrightarrow S^{-} \otimes R^{+}$: the interaction of decreased response latency and the reverberating circuits stands in direct relationship to the interaction of lowered response threshold and increased repetition.

5. The increase in psychological duration (D):
$D^{+} \leftrightarrow \otimes L^{-} Ctr^{+} R^{+} S^{-}$: the increase in psychological duration stands in direct relationship to the interaction of latency decrease, reverberating circuit strength, increase in repetition and threshold decrease.

These formulations may be treated as suggested correlations. For example, $T^{+} \leftrightarrow R \otimes B$ may be written as $T^{+} \llcorner R \otimes B$ where T^{+} is to be regarded as an intervening variable as long as no direct neurological evidence for it is available. A correlation between T^{+} and $R \otimes B$ becomes possible when its demonstration and quantification has materialized. Naturally, this would presuppose some far-reaching advances in a number of basic sciences. With further developments it may, of course, become unnecessary to retain the concept of "trace" altogether.

SUMMARY

This paper contains the postulation and theoretical development of two general concepts.

Psychological Duration, the first concept, is described as an hypothetical process which, under conditions of stress, is asynchronous with respect to objective or distal criteria of time flow.

Experimental evidence derived from a study of spontaneous aggression in homozyous mice suggests that an increase in psychological duration is one of the factors responsible for a decrease in fighting response latency.

The determiners of spontaneous fighting were subsumed under the generalized concept of Perceptual Homeostasis. This term describes the attempt of organisms to maintain environmental stimuli in an approximately balanced state. The hypothesis was advanced that aggression is the behavioral end process of an attempt at making the unpredictable moving opponent into a constant

and predictable stimulus. Perceptual homeostasis involves not only the search for cognitive stability in space, but additionally, it involves the predictability of events with respect to their starting and end points in time. Under conditions of emotional stress the state of psychological duration may affect and seriously disturb delay and anticipatory functions of the individual.

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ILLUSION AS A PROBLEM IN SYSTEMATIC PSYCHOLOGY

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As usually stated, even in psychological textbooks, the problem of Illusion is an epistemological one. That is to say, we are asked to account for the fact that perceiving sometimes fails to yield knowledge of reality. It is the purpose of this brief note to indicate how the problem may be stated in psychological terms.

To begin with, we must as psychologists turn away from the "correspondence" theory of cognition. We cannot say that "true" cognition corresponds with reality while false cognition does not. Since cognizing is an organic or personal activity, it should be immediately apparent that it cannot be similar to an object (the "real" object) which is not active and not organic or personal. In perceiving there is an acting *with reference to* an object or object-situation, but the acting is not the object nor similar to the object, any more than the batting is similar to the batted ball. (The nature of the object of perceiving is a topic by itself; I have elsewhere argued that the psychologist must take a naively realistic attitude towards objects.[1])

In place of the epistemological criterion of correspondence with reality, the psychologist has the category of determination. An act of perceiving (or thinking) is partly determined by the object, but, of course, partly by the person. Any given experience—or better, experiencing—must be placed somewhere on the continuum between complete objectivity (determination wholly by the objective situation) and complete subjectivity (determination wholly by the person). Pure objectivity and pure subjectivity are limits, almost certainly never realized.

This distinction, though it does not by itself yield a criterion of illusion or error, does open the way to a psychological treatment. Illusion or error is quite simply defined as a personal act *inadequately* determined. Now the traditional doctrine of illusion also used the concept of inadequacy; it spoke of an "inadequate copy of reality." This criterion, however, carries one clear outside the field of psychology and plump into that of epistemology, whereas the criterion of inadequate *determination* carries us back to the person. ***Illusion is knowing which is inadequate to the needs of the person.***

This conception is half-heartedly suggested in many of the psychological treatments which make visual illusion, for example, a matter of non-correspondence with other modes of apprehension, especially with kinesthesis. But why should we say that it is vision which is illusory? Why grant priority to the kinesthetic? Actually we do not. Perception is illusory when our perceiving activities do not hold together in the way required by personal needs.

Consider a few typical cases. In the bent-stick illusion, the act of perceiving is relatively completely determined by the pattern of light rays on the retina. It is objectively determined. Nonetheless, here is illusion, because apprehending the object in this way leads the person into trouble with his world.

On the other hand, the remarkable constancy with which we perceive shapes, colors, and sizes in defiance of great changes in the retinal images (*i.e.*,

[1] See "Naive psychological realism vs. critical realism," *J. Phil.*, 1926, 23, 682–685.

in defiance of the objective determiners of perceiving) is not reckoned as illusion or error. For it suits the needs of the person that the object be immediately apprehended as constant.

Again, we may have visual imagining which is almost wholly free from external control, that is, determined only in very minor degree by some trivial objective cue and to an enormous degree by personal desire; yet this imagining activity is not illusory so long as it is recognized by the person as imagining; that is to say, so long as he does not base his other acts unwisely on this act of imagining. In contrast, the so-called hallucinations of the insane are frequently very completely determined by objective factors; that they see snakes is due to actual patterns of light and shade that really do look snaky. Yet here the predominance of objective determiners does not save the activity from being gravely illusory.

In short, neither the epistemological concept of the fidelity of a "mental copy" to an objective reality (which can only be known by means of such copies), nor the more psychological concept of objective or subjective determination can provide us with an acceptable criterion of illusion. We must have recourse to the concept of *personal relevance*. Veridical perceiving is adjustive to the long-term needs of the person, illusory perceiving is maladjustive to those needs. Without the concept of the person and his needs, a distinction between illusion and "true" cognition cannot be made.

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AN IDEAL EQUATION OF FORGETTING DERIVED FOR OVERLEARNING

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The theory of the engram-complex, as formulated in a previous paper (5), assumes that percentage of retention n is proportional to the degree of activation of an associated engram-complex consisting of engram-units, each subject to inactivation and subsequent reactivation. For non-overlearned material or activity the time rate of change of activation percentagewise is given by the differential equation:

$$\frac{dn}{dt} = -an + bn(1 - n), \quad (1)$$

where a and b may be regarded as coefficients of decay and restoration respectively. The solution of (1) is

$$n = \frac{b - a}{b - ae^{-(b-a)t}}, \quad b > a, \quad (2)$$

where e is the transcendental number encountered in the calculus. The details of the solution, as well as the methods for estimating the magnitudes of a and b, are presented in the paper in which the concept of the engram-complex is introduced (5).

The molecular interpretation of the engram-complex as a distribution of spatially noncontiguous molecules within a neural network leads to the identification of an engram-unit with a highly complex molecule capable of assuming quasi-isomeric energy-states. An activated engram-unit is then a molecule in a state of excitation.[1]

The state of excitation of this molecular engram-unit is associated with a higher energy-level than obtains prior to its energizing or activation. In the previous paper, in which equation (2) was derived, only two energy levels were assumed: an energy-level E_1 corresponding to the energy-state of an activated engram-unit and an energy-level E_0 corresponding to that of an inactive or inactivated engram-unit.

The assumption of two energy-levels only, E_0 and E_1, is sufficient for the derivation of equation (2); no doubt, because equation (2) was intended to hold only for material or activity not subjected to overlearning. However, there is no reason to suppose a general limitation to two energy-levels, E_0 and E_1. On the contrary, the molecular interpretation of the engram-complex indicates the existence of higher energy-levels: $E_2, E_3, \ldots, E_n$.

On the assumption of the fundamentally molecular nature of the engram-unit, recognition of this fact makes it possible to generalize the theory of the engram-complex to cover overlearning. Out of this generalization will emerge an ideal derived equation for the course of forgetting of overlearned material or activity through time.

Learning to a criterion of 100 per cent mastery activates an engram-

[1] Isomeric molecules are composed of the same elements united in the same proportion by weight, but differing in some properties because of difference in structure. When a molecule is excited, its constituent atoms undergo temporary rearrangement. Hence, when a molecule is said to be capable of assuming quasi-isomeric energy-states, we mean that its distinct energy-levels correspond to significantly different and relatively stable configurations of the atoms constituting it (3, 5, 10, 11).

complex, the distributed collection of whose engram-units constitutes the ideal minimum number M of activated engram-units basic to performance of the learned activity. On the assumption of two energy-levels, overlearning is explainable only by the supplementary activation of engram-units beyond the attained minimum M. There is reason to believe that this does take place. However, even if this additional activation is involved in overlearning, the assumption by itself fails to account for the linearization of the curve of forgetting for overlearned material and the marked retardation of its descent to asymptotic values.

Let us, therefore, generalize the theory of the engram-complex to more than two energy-levels. To keep the mathematics tractable, we shall assume three energy-levels: E_0, E_1, and E_2, but no restorative processes. The effect of the latter can be surmised readily enough by graphical addendum to the plotted curve of the derived equation.

Learning to a criterion of mastery assumes the establishment of at least energy-level E_1 in M engram-units, where M is the minimal number corresponding to 100% performance. In the course of raising engram-units from E_0 to E_1, a number of already activated engram-units most certainly undergo elevation from E_1 to E_2. If only M engram-units can constitute an engram-complex, that is to say, if only M engram-units can be energized from E_0 to E_1, then overlearning means that energizing is concentrated on raising these already activated engram-units, and no others, from E_1 to E_2.

If, on the other hand, supplementary activation is also involved, as we may well surmise, additional engram-units are raised to E_1 concurrently. These are thereby drawn as members into the original engram-complex in the course of concomitant elevation of previously activated units from E_1 to E_2. Ultimately, with overlearning, supplementary activation must come to an end and E_2 be ideally the energy-level of all the constituent units of the engram-complex. If supplementary activation has been involved, then, at cessation of learning, $n > 100\%$.

Suppose that in either case all the engram-units have been raised to E_2. If we take as base, M, the minimum number of engram-units corresponding to a criterion of mastery, then the initial per cent of engram-units at E_2, on cessation of learning, may be represented by m where $m \geqslant 100\%$.

According to quantum theory, spontaneous reversion occurs successively from E_2 to E_1 and then from E_1 to E_0 —E_0 corresponding to inactivation. Furthermore, the rates of reversion from E_2 to E_1 and from E_1 to E_0 are in general different. Thus, we have, as a basic correlate to the process of forgetting, a process of progressive inactivation compounded of two reversions of energy-levels taking place in succession.

With the above in mind, we proceed to derive an *ideal* equation of forgetting for overlearned material when no restorative processes are in operation. Let $n_2 = \%$ of engram-units at E_2 at time t. Let $n_1 = \%$ of engram-units at E_1 *formed* up to time t. Let $n_0 = \%$ of engram-units at E_0 *formed* up to time t. Then, $n_1 - n_0 = \%$ of engram-units at E_1 *present* at time t.

If the rate of reversion from E_2 to E_1 percentagewise is proportional to the momentary percentage obtaining,

$$\frac{dn_2}{dt} = -cn_2, \qquad (3)$$

where c is the constant of proportionality. Since $n_2 = m - n_1$, substitution in (3) yields

$$\frac{dn_1}{dt} = c(m - n_1). \tag{4}$$

In other words, at any given time t, n_1 is increasing at a rate proportional to the value of n_2 at that time. Since, on exclusion of reversion from E_1 to E_0, $n_2 = m - n_1$, the differential equation for time rate of change of n_1 is that given by (4).

Similarly, at any given time t, n_0 is increasing at a rate proportional to the momentary percentage of engram-units at E_1 obtaining. Since the percentage of engram-units at E_1 is $n_1 - n_0$, the differential equation for time rate of change of n_0 is

$$\frac{dn_0}{dt} = a(n_1 - n_0), \tag{5}$$

where a is a constant of proportionality.

Equation (4), since it contains only one dependent variable, can be at once integrated. The solution of (4) is

$$m - n_1 = Ce^{-ct}, \tag{6}$$

where C is the constant of integration. Since at $t = 0$, $n_1 = 0$ ideally, evaluation of C leads finally to

$$n_1 = m(1 - e^{-ct}). \tag{7}$$

Substituting (7) in (5) leads to

$$\frac{dn_0}{dt} + an_0 = am(1 - e^{-ct}), \tag{8}$$

a differential equation which is linear in the dependent variable n_0.

Equation (8) is of the form,

$$\frac{dn_0}{dt} + Pn_0 = Q. \tag{9}$$

Multiplying both sides of (9) by the integrating factor,

$$R = e^{\int P dt}, \tag{10}$$

converts (9) into a form facilitating solution (8, 9). The solution, itself, will then be given by

$$n_0R = \int RQdt + C, \tag{11}$$

where C is the constant of integration.

Since $P = a$,

$$R = e^{at}. \tag{12}$$

Hence, substitution of (12) in (11) yields

$$n_0e^{at} = \int e^{at} \cdot am(1 - e^{-ct})dt + C. \tag{13}$$

Evaluating the integral in (13) leads finally to

$$n_0e^{at} = me^{at} - \frac{am}{a - c}e^{(a-c)t} + C. \tag{14}$$

Since $n_0 = 0$ when $t = 0$, we find

$$C = -\frac{cm}{c - a}. \tag{15}$$

Substituting (15) in (14) and dividing through by e^{at} yield the equation,

$$n_0 = m\left(1 + \frac{a}{c-a}e^{-ct} - \frac{c}{c-a}e^{-at}\right). \tag{16}$$

This equation is of first importance since it describes the percentage growth of engram-unit inactivation with time and, hence, the course, through time, of the correlated loss in retention.

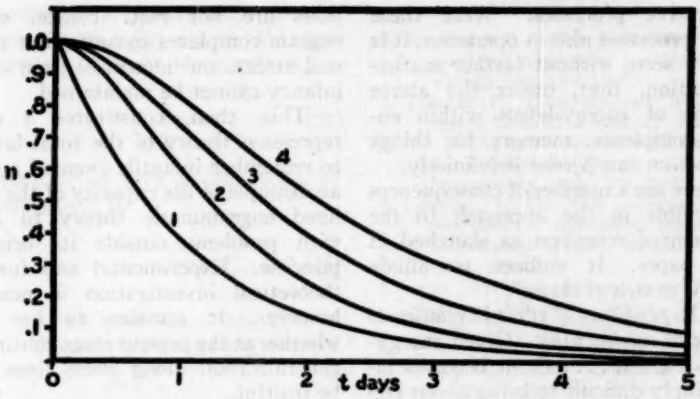
Let

$$n = m - n_0. \tag{17}$$

Substitution of (16) in (17) yields finally the desired ideal equation,

$$n = \frac{m}{c - a}(ce^{-at} - ae^{-ct}). \tag{18}$$

The magnitude of the constant a can be estimated for given material or activity by the method described in a previous paper (5). The value of c and m can then be adjusted to the data.



Equation (18) assumes an indeterminate form should $a = c$. However, on proceeding directly from equation (8) by means of the same method described above, we can arrive at an equation valid for this contingency. Therefore, if $a = c$, we arrive at

$$n = m(1 + at)e^{-at}. \qquad (19)$$

As was shown in the previous paper (5) for non-overlearned material, $a = 1/i_a$ where i_a = average duration of engram-unit activation at energy-level E_1 when no restorative processes are in operation. Similarly, $c = 1/i_c$ where i_c = average duration of initial engram-unit activation at energy-level E_2.

Thus, if we take $m = 1$, that is to say, if no supplementary activation has taken place and all engram-units in the complex are ideally at E_2, curves 2, 3, and 4 represent respectively three possibilities: $i_c < i_a$, $i_c = i_a$, and $i_c > i_a$. Curve 1 represents ideally the course of forgetting for non-overlearned material.[3]

[3] The reader is again reminded that restorative processes are excluded from consideration. Hence, the otherwise inadmissible asymptotic $n = 0$.

In curve 1, i_a is taken, for illustrative purposes, as equal to one day. Its equation is, therefore,

$$n = e^{-t}. \qquad (20)$$

In curve 2, $i_a = 1$ and $i_c = 1/2$. Appropriate substitution in (18) shows that its equation is

$$n = 2e^{-t} - e^{-2t}. \qquad (21)$$

In curve 3, $i_a = i_c = 1$. Corresponding substitution in (19) yields

$$n = (1 + t)e^{-t}. \qquad (22)$$

In curve 4, $i_a = 1$ and $i_c = 1.5$. Appropriate substitution in (18) yields, on simplification,

$$n = 3e^{-2t/3} - 2e^{-t}. \qquad (23)$$

We note the increasing linearization of the curve of forgetting and the concomitant retardation in its descent with relative increase of i_c over i_a.

If supplementary activation is taken as having occurred, then $m > 1$. In this contingency equations (21), (22), and (23) must be multiplied by a constant—the value of m. This results graphically in the bodily shift of the curves upward with consequent marked increase of retention over time, even with ideal exclusion of

restorative processes. Were these latter processes also in operation, it is readily seen, without further mathematization, that, under the above scheme of energy-levels within engram-complexes, memory for things and action can persist indefinitely.

There are a number of consequences discernible in the approach to the problem of retention as sketched in this paper. It suffices to allude briefly to two of them.

1. *Expenditure of effort in relation to degree of overlearning.* Given energy-levels $E_0, E_1, \ldots, E_n$, it becomes increasingly difficult to bring about elevations to successively higher levels. We should, accordingly, anticipate increasingly uneconomical expenditure of effort to accompany increasing degree of overlearning. This prediction is in accord with the known data of experiment.

2. *Memory of events in infancy.* If we assume the fundamentally molecular nature of the engram-unit, then, as previously shown (1, 4, 5, 7, 11), rate of forgetting turns out to be a function of internal body temperature as well as of other variables. It is known that elevation of temperature increases rate of spontaneous reversion of energy-levels. Therefore, in accordance with the molecular interpretation of the engram-complex, one must conclude that rate of forgetting accelerates with temperature increase.

We may regard the individual as immersed in a heat bath—his own. To combat the deleterious effect of sheer body heat on the integrity of the engram-complexes requires (1) that the constituent engram-units of the latter be activated to sufficiently high energy-levels and (2) that appropriate restorative processes have been formed and are in effective operation. In the infant we have every reason to conjecture that these two conditions are not met. Hence, early engram-complexes cannot resist thermal attack and memories from early infancy cannot be maintained.

This, then, constitutes a non-repression theory of the total failure to remember infantile events,[3] and is an example of the capacity of the outlined engrammatic theory to cope with problems outside its original purview. Experimental and further theoretical investigation is needed, however. It remains to be seen whether at the present stage continued generalization along these lines can be fruitful.

Mathematical Note

The process of reversion at one rate from E_2 to E_1 and, then, at another rate, from E_1 to E_0 serves to build up $n_1 - n_0$ at E_1 to a momentary maximum before falling off subsequently. This maximum is calculable, as well as the time of its attainment, assuming, as always, no restorative processes in operation.

Subtracting (16) from (7), we have

$$n_1 - n_0 = \frac{cm}{a - c}(e^{-ct} - e^{at}). \quad (24)$$

Differentiating with respect to t, we obtain

$$\frac{d}{dt}(n_1 - n_0) = \frac{cm}{a-c}(ae^{-at} - ce^{-ct}). \quad (25)$$

Setting (25) equal to zero in order to maximize, we find, on simplification, that

$$t = \frac{\ln(c/a)}{c - a}, \quad c \neq a, \quad (26)$$

that is to say, t, as given by (26), is the time at which $n_1 - n_0$ attains its maximum.

[3] The selective forgetting which subsequently characterizes early childhood memories is, of course, another matter, though thermal deterioration of engram-complexes continues to be a factor.

It remains to ascertain the value of this maximum. On setting (25) equal to zero, we have, on transposition,

$$e^{-at} = \frac{c}{a} e^{-ct}. \qquad (27)$$

Substitution of (27) in (24) leads, on simplification, to

$$n_1 - n_0 = \frac{cm}{a} e^{-ct}. \qquad (28)$$

If $c \neq a$, we may substitute (26) in (28). Therefore, recollecting that

$$e^{\ln x} = x,$$

we have, on appropriate simplification,

$$n_1 - n_0 = m(c/a)^{a/(a-c)}. \qquad (29)$$

The formula, as given by (29), gives the desired maximal percentage of engram-units at energy-level E_1.

Utilizing (7), (17), and (19), similar procedure leads, in the case where $c = a$, to the maximum,

$$n_1 - n_0 = m/e \quad \text{at} \quad t = 1/a. \qquad (30)$$

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THE APPLICATION OF THE METHOD OF PAIRED COMPARISONS TO THE STUDY OF REACTION POTENTIAL

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L. L. Thurstone (5, 6, 7) made a distinct contribution to the science of psychology when he introduced his technique of scaling data obtained by the Method of Paired Comparisons. Although the technique was early used in typical "psychophysical" experiments, probably its greatest value has been in the quantification of behavior which was *not* clearly correlated with any easily discoverable physical antecedent variables (2, p. 217). Recently, however, Hull and associates (4) have utilized the technique in a quite different context (both theoretical and experimental) from that set forth by Thurstone. Although Hull took over Thurstone's algebra, he gave quite a different theoretical signification to the symbols used. This shows that, in a certain abstract sense, the mathematical development of the quantificational technique is independent of any specific theory of behavior. Since Hull's application of the technique will probably be used increasingly in the near future, this paper will be stated in his language. The algebraic development, however, may be of interest to any researchers who use the Method of Paired Comparisons—in quantitative behavior theory, in psychophysics, or in social psychology.

Although Hull's description of the actual mechanics of quantification of reaction potential (4) needs no supplement, it should be noted that the theoretical basis of the technique is there presented in a form limited to the particular conditions of the experiment: *i.e.*, constant, primary drive; constant, small reinforcement; regular, distributed trials, etc. (1). In terms of Hull's theory, however, the technique is quite applicable to many different antecedent conditions. The drive may be primary or secondary, variable or constant. The reinforcement may be of any amount, even zero, constant or variable, primary or secondary. The trials may be spaced in any manner, etc. In their pioneer article, Hull *et al.* (4) were concerned with the quantification of habit strength in terms of reaction potential with constant drive. Since others may wish to apply their technique to quite different conditions, the first purpose of this article is to state the most general set of postulates from which the quantification of *effective reaction potential* may be deduced for any experiment.

The equations for estimating σ_k, which Hull *et al.* took over from Thurstone, are only simple first approximations. This fact lends importance to the following possibilities: (1) There may be more complicated but more exact formulas to which Thurstone's would reduce as a first approximation. (2) There may be other first approximations, just as valid as Thurstone's, but requiring less arithmetic. The second purpose of this paper is to present an example of the second alternative. It is hoped

[1] The writer expresses his deepest gratitude to his colleagues, Dr. Harold D. Hantz and Dr. Sol M. Roshal, for technical criticism, and to Miss Cleta Stuart for preparation of the typescript.

that the demonstration that more than one approximation exists may stimulate the mathematically inclined reader to further research on this problem. While approximate formulas may be adequate to obtain certain desired equations, more exact ones may be needed to settle such questions as whether the probability distribution of momentary effective reaction potential is leptokurtic or normal (8).

STATEMENT OF POSTULATES

The following postulates, obtained from an analysis of the papers of Thurstone (6, 7) and of Hull *et al.* (4) and of Guilford's book (2), may be stated as follows:

(1) Momentary effective reaction potential ($_s\mathring{E}_r$) is a monotonic decreasing function of momentary reaction latency ($_s\mathring{t}_r$) and conversely.

(2) At any given trial, the probability distribution of $_s\mathring{E}_r$ about the mean effective reaction potential ($_s\bar{E}_r$) is approximately normal.

(3) The above-mentioned probability distributions at any two trials are uncorrelated.

(4) The standard deviations (σ_k) of all the above-mentioned distributions are of the same order of magnitude.

(5) The unit of reaction potential is proportional to the mean of all the above-mentioned standard deviations ($\bar{\sigma}$).

The postulates, so far, refer to a single organism. In order to give them practical application, another postulate is required:

(6) The comparisons of the latencies of any two trials of a given subject may be pooled with comparable data from other subjects (in an approximately homogeneous group of organisms) to give data describing a hypothetical average member of the group.

These postulates are supplemented by two definitions:

(1) The ratio of the unit of reaction potential to the mean of the above-mentioned standard deviations is defined as 1.

(2) The arbitrary zero of the scale values is defined as the value at the first trial of the conditioned response.

From these postulates and definitions, together with a few other definitions and theorems of statistical theory and logic, the entire mathematical basis for the quantification of reaction potential may be deduced.

The reader may notice that the only constructs of Hull's theory that are mentioned here are momentary effective reaction potential ($_s\mathring{E}_r$) and effective reaction potential ($_s\bar{E}_r$). None of the others which are introduced in his book (3) need be mentioned in the postulates for quantifying $_s\mathring{E}_r$. The quantificational postulates are believed to be logically independent of the others; for example, that governing the growth of habit strength.

THE BASIC EQUATION

Hull (4) has shown that the problem of quantifying the effective reaction potential (measured from an arbitrary zero) at any trial may be approached by first determining the difference between the effective reaction potentials of any two adjacent trials. Then, by adding up successive increments, the desired values for all trials may be obtained.

Consider any two trials, x and y. By postulate 2, both $\mathring{E}_x$ and $\mathring{E}_y$ are normally distributed about their respective means $\bar{E}_x$ and $\bar{E}_y$, with standard deviations σ_x and σ_y. Therefore, the momentary differences $(\mathring{E}_x - \mathring{E}_y)$ are normally distributed about their mean $(\bar{E}_x - \bar{E}_y)$ with a standard deviation σ_{xy}. By a well known theorem

of statistics and postulate 3,

$$\sigma_{xy} = \sqrt{\sigma_x^2 + \sigma_y^2}. \quad (1)$$

For any given subject, if $\hat{E}_x > \hat{E}_y$, then, by Postulate 1, $i_x < i_y$, and conversely.

According to Postulates 6 and 1, by finding empirically the probability (for the group) that momentary latency at trial x is *less than* that at trial y we have thus determined the probability that momentary effective reaction potential at trial x is *greater than* that at trial y.

$$P(\hat{E}_x > \hat{E}_y) = P(i_x < i_y). \quad (2)$$

Postulate 2 allows us to use a table of the normal probability integral to find the number (X_{xy}) of standard deviations of difference (σ_{xy}) between the means. By definition of X_{xy},

$$X_{xy} = \frac{\bar{E}_x - \bar{E}_y}{\sigma_{xy}}. \quad (3)$$

Therefore, from equations 1 and 3,

$$\bar{E}_x - \bar{E}_y = X_{xy}\sqrt{\sigma_x^2 + \sigma_y^2}. \quad (4)$$

Equation 4 is the basic equation for the solution of the problem. The value of X_{xy} for *any two trials* is readily determined. The crux of the problem, therefore, is the technique for estimating the values of the sigmas. Following Hull (4) we shall confine ourselves to Thurstone's "Case III" (6, 7).

THURSTONE'S METHOD OF ESTIMATING σ_k

Consider any three trials, h, j, and k. Trials h and j are to be held constant, once chosen, while k is to be considered a variable.

By applying equation 4, therefore,

$$\bar{E}_k - \bar{E}_h = X_{kh}\sqrt{\sigma_k^2 + \sigma_h^2}, \quad (5)$$

$$\bar{E}_k - \bar{E}_j = X_{kj}\sqrt{\sigma_k^2 + \sigma_j^2}. \quad (6)$$

By subtraction and rearrangement,

$$X_{kj} = \left(\frac{\sqrt{\sigma_k^2 + \sigma_h^2}}{\sqrt{\sigma_k^2 + \sigma_j^2}}\right) X_{kh} - \left(\frac{\bar{E}_j - \bar{E}_h}{\sqrt{\sigma_k^2 + \sigma_j^2}}\right). \quad (7)$$

Equation 7 deserves careful consideration. Since k is the only variable subscript, the only variables are X_{kj}, σ_k, and X_{kh}. Equation 7 says that X_{kj} is a joint function of X_{kh} and σ_k. The other symbols, σ_h, σ_j, $\bar{E}_j$, and $\bar{E}_h$, are parameters.

At this point, Postulate 4 allows us to introduce an approximation (6, p. 281):

$$\sqrt{\sigma_k^2 + \sigma_j^2} \doteq \frac{\sqrt{2}}{2}(\sigma_k + \sigma_j). \quad (8)$$

A similar equation holds for σ_h and σ_k. Substitution of these approximations into equation 7 gives

$$X_{kj} \doteq \left(\frac{\sigma_k + \sigma_h}{\sigma_k + \sigma_j}\right) X_{kh} - \left(\frac{\sqrt{2}(\bar{E}_j - \bar{E}_h)}{\sigma_k + \sigma_j}\right). \quad (9)$$

Postulate 4 also allows another first approximation: We may set σ_k equal to the mean of the sigmas, which, by Postulate 5 and Definition 1, equals 1.00.

$$\therefore \quad X_{kj} \doteq \left(\frac{1 + \sigma_h}{1 + \sigma_j}\right) X_{kh} - \left(\frac{\sqrt{2}(\bar{E}_j - \bar{E}_h)}{1 + \sigma_j}\right). \quad (10)$$

Equation 10 states that X_{kj} is approximately a linear function of X_{kh}. Analytic geometry tells us that the slope of this line is given approximately as

$$m \doteq \frac{1 + \sigma_h}{1 + \sigma_j}. \quad (11)$$

Equation 10 implies that there is approximately perfect correlation be-

tween X_{kj} and X_{kk}. By a well-known theorem of statistics, the slope (m) also is given approximately as

$$m \doteq \frac{V_j}{V_k}, \tag{12}$$

where V_k is defined as

$$V_k \equiv \sqrt{\frac{1}{N}\sum_{k=1}^{N} X_{kk}^2 - M_k^2}, \tag{13}$$

$$M_k \equiv \frac{1}{N}\sum_{k=1}^{N} X_{kk}. \tag{14}$$

In these formulas N equals the total number of trials the data of which are being scaled. Replacing k by j in equations 13 and 14 allows us to calculate M_j and V_j.

By equations 11 and 12,

$$\therefore \quad \frac{1+\sigma_k}{1+\sigma_j} \doteq \frac{V_j}{V_k}. \tag{15}$$

$$\therefore \quad V_k(1+\sigma_k) \doteq V_j(1+\sigma_j). \tag{16}$$

Up to this point k and j have been held constant. But since equation 16 is true for any integral values of k and j from 1 to N, each side equals a constant, defined as a. Using the dummy index k we may therefore write:

$$V_k(1+\sigma_k) \doteq a; \tag{17}$$

$$\therefore \quad \sigma_k \doteq (a/V_k) - 1. \tag{18}$$

The constant a may be evaluated by summing equation 18 for all values of k from 1 to N.

$$\Sigma\sigma_k \doteq a\Sigma(1/V_k) - N. \tag{19}$$

But by Postulate 5 and Definition 2,

$$\bar{\sigma} \equiv \frac{1}{N}\Sigma\sigma_k = 1; \tag{20}$$

$$\therefore \quad \Sigma\sigma_k = N. \tag{21}$$

By using equations 19 and 21 and solving for a,

$$a \doteq \frac{2N}{\Sigma(1/V_k)}. \tag{22}$$

Equations 18 and 22 constituted Thurstone's major contribution in this area.

Once the constant a is evaluated by equation 22, σ_k for each value of k is calculated from equation 18. Then, using equation 4, the differences between the effective reaction potentials of any two adjacent trials may be calculated. By using Definition 2 and adding up successive increments of difference between values of adjacent trials, the scale value of any trial may be calculated. In practise this is not done so simply. The difference between any two adjacent trials also may be found indirectly by subtraction, as Hull (4) shows, following Thurstone. These various estimations of the same difference do not always agree exactly. It is customary to take the mean difference to get the best estimate of the difference between the scale values of any two adjacent trials although the median difference could be used. The choice of the best central tendency of difference is a matter for statistical theory to decide.

THE NEW METHOD OF ESTIMATING σ_k

Up through equation 7, the new analysis proceeds as before. The approximation given in equation 8, however, is *not* introduced. The approximation involved in setting σ_k equal to 1 is, however, used. Thus equation 7 becomes

$$X_{kj} \doteq \left(\frac{\sqrt{1+\sigma_k^2}}{\sqrt{1+\sigma_j^2}}\right) X_{kk} - \left(\frac{\bar{E}_j - \bar{E}_k}{\sqrt{1+\sigma_j^2}}\right). \tag{23}$$

This says that X_{kj} is approximately a linear function of X_{kk} with slope

$$m \doteq \frac{\sqrt{1+\sigma_k^2}}{\sqrt{1+\sigma_j^2}}. \tag{24}$$

By combining this with equation 12,

$$\frac{\sqrt{1+\sigma_k^2}}{\sqrt{1+\sigma_j^2}} \doteq \frac{V_j}{V_k}. \quad (25)$$

$$\therefore \quad V_k\sqrt{1+\sigma_k^2} \doteq V_j\sqrt{1+\sigma_j^2}. \quad (26)$$

$$\therefore \quad V_k^2(1+\sigma_k^2) \doteq V_j^2(1+\sigma_j^2). \quad (27)$$

Equation 27 implies that each side approximately equals a constant (defined as b) just as did equation 16. Using the dummy index k:

$$V_k^2(1+\sigma_k^2) \doteq b. \quad (28)$$

Instead of attempting to evaluate b, we shall square both sides of equation 17 and subtract equation 28 from this.

$$V_k^2(1+2\sigma_k+\sigma_k^2) \doteq a^2,$$
$$V_k^2(1+\sigma_k^2) \doteq b;$$
$$\therefore \quad 2V_k^2\sigma_k \doteq a^2 - b;$$
$$\therefore \quad V_k^2\sigma_k \doteq c, \quad (29)$$

where, by definition,

$$c \equiv (a^2 - b)/2. \quad (30)$$

Since both a and b are approximately constants, so is c.

$$\therefore \quad \sigma_k \doteq c/V_k^2. \quad (31)$$

The constant c may be evaluated by summation:

$$N = \sum\sigma_k \doteq c\sum(1/V_k^2);$$
$$\therefore \quad c \doteq \frac{N}{\sum(1/V_k^2)}. \quad (32)$$

Equations 31 and 32 should be compared to their predecessors, equations 17 and 18, respectively. The new equations demand appreciably less labor of computation, since it is not necessary to take the square root of each value of V_k^2. Since the new formulas are deduced from the same postulates from which the old ones are obtained, the new ones may claim equal validity with the old ones.

EMPIRICAL TEST OF THE NEW FORMULAS FOR ESTIMATION OF σ_k

In order to test experimentally the validity of the new equations for estimating σ_k, it was decided to calculate the scale values (effective reaction potential measured from an arbitrary zero) of a set of data whose scale values had already been determined by use of the old formulas. Theoretically, the corresponding scale values for each trial should be equal. If the new values are plotted against the old ones, the plotted points should fall closely about a straight line extending from the origin with a unit slope.

To diminish the amount of computational work, the data presented by Hull *et al.* for nine trials of 59 rats were used (4, Tables 5 and 6, pp. 245, 247).

Table I shows the values of $1/V_k^2$ for each of the nine trials. These values were obtained by squaring the

TABLE I

THE COMPARISON OF THE VALUES OF σ_k OBTAINED BY TWO DIFFERENT METHODS. Values of $1/V_k^2$ were obtained by squaring Hull's values of $1/V_k$.

Hull *et al.* (4, p. 247)		Burros	Hull *et al.*
k	$1/V_k^2$	σ_k	σ_k
1	5.683	1.114	1.123
2	5.420	1.063	1.073
3	4.297	0.843	0.846
4	3.236	0.635	0.602
5	7.076	1.388	1.369
6	5.194	1.019	1.030
7	4.765	0.934	0.944
8	4.227	0.829	0.831
9	5.998	1.176	1.181
Total	45.896	9.001*	8.999*

* Errors from rounding off decimals presumably account for the fact that these totals do not exactly equal the theoretical value (9.000).

corresponding values in Hull's Table 6 (4, p. 247).

The value of the parameter c was estimated from Table I and equation 32 as follows:

$$c \doteq \frac{N}{\Sigma(1/V_k^2)} = \frac{9}{45.896} = 0.1961.$$

The values of σ_k were then obtained by applying this value of c in equation 31 to each value of $1/V_k^2$ in Table I. Table I also gives the nine values of σ_k calculated from the older formulas (by Hull *et al.*) and from the present ones. It should be noted that the deviations are small. Discrepancies are found only in the second or third decimal place.

In the fourth and fifth comparisons of σ_k in Table I, the writer's values are greater than those of Hull *et al.* In the other seven comparisons of σ_k the reverse is true. If we assume the null hypothesis that the true probability of a difference in either direction is 0.5, then we can test it by using the point binomial, $(0.5 + 0.5)^9$. The probability of seven or more cases of inequality as given here is $46/512 \doteq 0.09$ (one-tailed test). The probability of a deviation as large or larger in either direction from the expected value (two-tailed test) is thus approximately 0.18. Therefore the differences in the values of σ_k obtained by the two techniques could easily arise by chance.

It was therefore expected that the new scale values (obtained by following Hull's directions but using the new values of σ_k) would agree closely with the old ones. Table II shows the scale values obtained by both techniques for each of the nine trials. By Definition 2, the zero of both sets of values is placed at that of the first trial. It can be seen that the scale values do agree to the first decimal place and are not very different in the second. Guilford (2, p. 234) says that the scale values are "strictly accurate only to the first decimal place."

TABLE II

THE COMPARISON OF THE SCALE VALUES OBTAINED FROM TWO DIFFERENT METHODS OF ESTIMATING σ_k

Trial No.	Hull *et al.*	Burros
1	0.0000	0.0000
2	0.0700	0.0694
3	0.3438	0.3399
4	0.6974	0.6894
5	0.8557	0.8428
6	0.7338	0.7202
7	1.3206	1.3050
8	1.3820	1.3681
9	1.8764	1.8609

Even though the deviations are small, however, there is a systematic trend. Since the values at the first trial are both zero by definition, we may legitimately make comparisons only within the other eight pairs of values. Table II shows that, in all eight pairs, the values of Hull *et al.* are greater than those of the writer. The one-tailed probability calculated from the point binomial is 1/256. The two-tailed probability is thus 1/128. The trend is therefore significant at the one per cent level. Although the differences are statistically significant, however, they are not of practical importance in computation, since they are relatively small.

To save space, no graph is presented. The reader may plot the new values against the old ones to check the following statements:

1. The points fall closely upon a straight line drawn from the origin through the last point.

2. This line has a slope of 0.9917 which differs from the theoretical slope (1.0000) by only 0.0083. This is well less than one per cent error.

SUMMARY AND CONCLUSIONS

1. A general set of postulates, based upon Hull's theory of behavior, is presented as the theoretical basis of the quantification of effective reaction potential. These postulates are believed to be logically independent of those dealing with other constructs such as habit strength, drive, etc.

2. The derivations of the approximate formulas for estimation of $\sigma_{\bar{x}}$, first written by Thurstone, are restated in terms of Hull's theory.

3. From the same postulates, alternative approximate formulas are deduced for the estimation of $\sigma_{\bar{x}}$. These have the following properties:

(a) They yield nearly the same values of $\sigma_{\bar{x}}$ as do Thurstone's formulas; the new scale values based on the new $\sigma_{\bar{x}}$ values are slightly but significantly less than the old ones;

(b) They are presumably as valid as those of Thurstone;

(c) They involve less labor of computation;

(d) Although derived here in terms of Hull's theory, their algebra may be considered independently of any particular theory of behavior;

(e) Therefore the newer formulas may have application not only in quantitative behavior theory but also in psychophysics and in social psychology.

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